



Effect of Virtual Reality-Based Rehabilitation on Physical Fitness in Patients with Chronic Obstructive Pulmonary Disease

by

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The aim of the study was to evaluate the effects of rehabilitation in patients with chronic obstructive pulmonary disease (COPD) using the Kinect system during stationary rehabilitation. The study included 68 patients with COPD (35 men, 33 women, mean age 61.3 ± 3.7). The subjects were randomly assigned to one of the two experimental groups described below. Group I included 34 patients – non-participants in Kinect training. Group II included 34 patients – participants in Kinect training. In all patients before and after rehabilitation physical fitness was assessed using the Senior Fitness Test (SFT). The Xbox 360 and Kinect motion sensor were used to carry out virtual reality training. In group I, statistically significant improvements in SFT performance were observed. Patients in group II also showed statistically significant improvement in physical fitness in all attempts of the SFT. Virtual rehabilitation training in patients with COPD seems to be a practical and beneficial intervention capable of enhancing mobility and physical fitness.

Key words: virtual rehabilitation, COPD, physical fitness, virtual reality, pulmonary rehabilitation.

Introduction

The main symptoms of chronic obstructive pulmonary disease (COPD) include cough, mucus or mucopurulent secretion, and dyspnea. However, as the condition evolves over time, impaired lung ventilation and breathing mechanics lead to the occurrence of dyspnea on exertion and then even at rest. The patient tries to trigger additional inspiratory muscles, especially sternocleidomastoid muscles, to even out the breath. In the advanced stages of COPD, characteristics of severed pulmonary distension are visible, including the appearance of barrel-shaped chest, enlargement of its antero-posterior dimension, horizontal ribs and increased intervals between them (Aliverti et al., 2005; Egan et al., 2012; Nici et al., 2006; Vestbo et al., 2013). Patients present reduced bone density (in 50-70% of

patients) and suffer from skeletal muscle disorders (in 30% of patients) (Ansari et al., 2007; Patel and Hurst, 2011; Seymour et al., 2010; Vilaro et al., 2009). In the literature, muscle dysfunctions in lower extremities are observed in patients with COPD in the example of the quadriceps muscle in the thigh. The test results indicate a decrease in strength and endurance of this muscle, compared to healthy people of similar age.

Comprehensive treatment of patients with COPD comprises rehabilitation, pharmacological treatment undertaken with the purpose of reducing the severity of symptoms and disease exacerbations, anti-smoking therapy, psychotherapy and oxygen therapy (Casaburi et al., 2009). According to Global Initiative for Obstructive Lung Disease (GOLD) guidelines, optimal benefits from pulmonary rehabilitation

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(PR) are obtained in a program lasting from 6 to 8 weeks. There is no evidence that extending the PR program to 12 weeks can provide further health benefits. Hence, it can be assumed that the PR program should include: elements of an exercise regimen conducted on a cycloergometer or a treadmill, breathing exercises including those performed to provide relaxation of the respiratory muscles, an exercise program designed to strengthen the diaphragm and improve respiration, all coupled with chest patting, general motor coordination and balance training, strengthening peripheral muscles in the upper and lower limbs, inhalations, drainage positions, relaxation as well as walking exercise (GOLD, 2017). A key role is attributed to the adequate selection of an appropriate level of exercise which is determined in detail when patients are qualified for a rehabilitation program. The applied models of pulmonary rehabilitation vary in intensity, duration and form of physical activity undertaken by patients (Casaburi et al., 2009; Jastrzębski et al., 2017; Kucio et al., 2016; Zwerink et al., 2013). Some studies, however, emphasize that the improvement of the functional status is temporary and the positive effects last up to 6 months following the program (Egan et al., 2012; Gottlieb et al., 2011; Román et al., 2013; Verril et al., 2005).

In the literature, reports regarding the potential application of new technologies in the therapeutic process, including virtual reality (VR), may be found. VR is based on the application of computer programs which record movement patterns using a three-dimensional camera or sensors placed on the body during exercise, followed by the transfer of the data to a computer-generated environment. The majority of research regarding VR focuses on the analysis of the therapeutic potential of standard virtual games, ones that are not in principle designed for clinical use. While playing such games that mostly involve movement to support functions of the body, there can be found similarities to the exercises performed during standard therapeutic programs. Throughout the play, dynamic changes in the body position are performed and recorded in 3D, and subsequently transferred to an avatar in virtual space. Hence, it can be assumed that use of VR can also increase the available range of rehabilitation programs for people with disabilities.

The use of virtual reality in rehabilitation has also become one of the new challenges for physiotherapists and software developers, whose task is to develop rehabilitation programs for patients with various conditions and dysfunctions of the musculoskeletal system. VR technologies have been explored as a possible adjunct to physical rehabilitation programs (Bonnechère et al., 2016; Jastrzębski et al., 2018; Kiper et al., 2018). The use of VR in the analysis of breathing mechanics has been also considered (Harte et al., 2016; Xia and Siochi, 2012) as well as in the training process involving patients with pulmonary problems (LeGear et al., 2014; Wardini et al., 2013).

To date, no comprehensive studies have been conducted focused on stationary pulmonary rehabilitation programs for patients with COPD using the VR environment. Therefore, this study aimed to propose modern exercise rehabilitation methods for COPD patients by adopting virtual rehabilitation systems. Global trends indicate new technologies as very effective in rehabilitation. The American College of Sport Medicine states that modern technologies, as a trend for 2017-2018, are the most effective way to increase physical activity of adults. Hence, searching for new, attractive technologies that would promote physical activity with proven effectiveness can be beneficial. The premise of this study was to solve an important problem in rehabilitation – how to motivate COPD patients, who are elderly people, to perform regular physical fitness exercises. This problem becomes real when a patient returns from hospital to home and loses the regular supervision of hospital staff. Exercise that is performed in a form of a game may seem much more attractive and provides a higher probability that a patient will follow the physiotherapist's prescriptions.

Methods

Participants

The study involved 68 patients diagnosed with COPD. Group I consisted of 34 patients (18 men and 16 women) participating solely in a standard pulmonary rehabilitation program. The average age of patients was 62.1 years (\pm 2.9). Group II included 34 patients (17 men and 17 women), with the average age of 60.5 years (\pm 4.3). Patients from group II participated in standard

pulmonary rehabilitation, additionally taking part in daily training using the Kinect system. The study was carried out between August 2015 and November 2016. The randomization procedure was conducted on the basis of a computer program. The groups were similar at baseline regarding the most important prognostic indicators. All patients for whom outcome measures were available received the treatment. The inclusion criteria were: 1) women and men aged 50-70 years; 2) diagnosed with COPD in categories B and C of GOLD. The exclusion criteria were: 1) lack of consent to participate in the research; 2) age below 50 and above 70 years; 3) pneumonia, tuberculosis and other respiratory inflammatory disease in all stages and forms; 4) condition after a heart attack; 5) diabetes; 6) state after thoracic and cardiac surgery, heart failure (stage III, NYHA class IV); 7) advanced hypertension; 8) diseases and injuries that could impair the function of the musculoskeletal system of transportation; 9) cognitive disorders, Mini-Mental State Examination < 24. Participants were fully informed about the purpose and procedures of the study and that they could withdraw at any stage of the experiment. Before testing, a physiotherapist explained the protocol thoroughly and demonstrated how the task should be performed correctly. The study was approved by the Bioethics Committee of the Chamber of Physicians in Opole (resolution no. 199 from February 7, 2013). The research was registered in the Australian New Zealand Clinical Trials Registry: ACTRN12617000275369.

Measures

The Senior Fitness Test (formerly also called the Functional Fitness Test or Fullerton test) was undertaken by all patients prior to and after the rehabilitation program. This test is one of the few existing tools that provide an easy and quick assessment of the components of physical condition. Six motor tasks were included: cardiorespiratory endurance, flexibility, agility, balance, motor coordination and exercise tolerance (Rikli and Jones, 2002). All trials performed throughout the tests were conducted with a physiotherapist. Each SFT trial was performed twice and the better of the two scores was recorded for further analysis.

The virtual rehabilitation program used a Xbox 360 console, along with the Kinect motion

sensor. The setup used in the test consisted of a console, a motion sensor and a projector with speakers. The height of the console was determined to be one meter, and it was placed on a table. The Kinect motion sensor was placed on the projector, which projected images on a wall located 2.5 m away. The playing area was at least 1.8 m wide and 1.8 m long and was located 1.2 m from the Kinect sensor. The patients participated in minigames, as part of Kinect Adventures, in which they performed certain movements in front of the motion sensor. It involved rafting, cross-country running, hitting a ball projected towards the player, and a roller-coaster ride. Before each game started, the instructions of the game manufacturer were displayed, detailing the objective and control of the avatar.

Design and Procedures

Prior to the test, patients were subjected to initial assessment including evaluation of their exercise tolerance and physical condition, and on this basis they were assigned to PR. All patients meeting the inclusion criteria were then consecutively and randomly assigned to the groups. Randomization (ratio 1:1) was performed using the Research Randomizer, a free web-based service that offers instant random sampling and random assignment. Group I comprised patients following a standard PR program, while group II included patients participating in a standard PR program who additionally performed exercises using the Kinect system training once a day.

After completing the research program (14 days), patients from both groups were subjected to another examination to assess their exercise tolerance, lung ventilation, dyspnea and physical fitness.

insert Figure 1 here

Statistical Analysis

The results were collected in an Excel spreadsheet and subsequently subjected to statistical analysis using STATISTICA 12 software. With respect to the basic descriptive characteristics, the arithmetic mean and standard deviation were derived. As normality tests (Lilliefors test) revealed that none of the SFT trials followed a normal distribution, non-parametric-tests were used. The baseline characteristics of the groups were compared using the Mann-Whitney U test. The difference in the mean values with regard to physical fitness was assessed with the

Wilcoxon test for within-group analysis and the Mann–Whitney U test for between-group analysis. The size of the between-group effects was determined by Cohen's d effect size and classified as: >.20 small, >.50 moderate and >.80 large effect size (Cohen, 1988).

We used G*power 3.1.7 software to calculate the sample size. Calculation was based on the F test, the type I error rate was set at 5% (alpha-level 0.05), the effect size of the main outcomes was 0.30, and the type II error rate gave 85% power. Considering a 15% drop-out rate, the appropriate minimum sample size for this study was 28 subjects. The statistical significance level was set at $p < 0.05$ for all tests.

Results

The effect of pulmonary rehabilitation is summarized in Table 3. Overall, it can be seen that after PR participants achieved better scores on the SFT. In both groups post-test measures of physical fitness improved significantly.

The number of repetitions of the Arm Curl test increased significantly from 19 to 20.6 in

group I and from 18.6 to 21.8 in group II, after PR ($p < 0.05$). The number repetitions of the Chair Stand increased significantly from 14.8 to 15.6 in group I and from 14.3 to 16.6 in group II, after PR ($p < 0.05$). The change in Back Scratch results after PR was significantly greater in both groups from -7.6 to -6.9 cm in group I and from -6.1 to -4.0 cm in group II ($p < 0.05$). In the Sit and Reach test both groups improved significantly from 0.1 to 1.3 cm in group I and from 0.7 to 3.4 cm in group II ($p < 0.05$). The total time of the Up and Go test decreased significantly from 6.3 to 6.0 s in group I and from 6.0 to 5.3 s in group II ($p < 0.05$). We also observed that the results of the 6-minute walk test in both groups were significantly higher, from 494.9 to 514.7 m in group I and from 469.9 to 508.4 m in group II ($p < 0.05$).

Between-group analysis showed statistically larger improvements in the Sit and Reach and Up and Go tests in group II. However, the results of the Sit and Reach test of group I during initial assessment were significantly lower (0.0 ± 4.2 vs. 0.7 ± 10.1 , $p < 0.03$).

Table 1

<i>Characteristics of participants</i>			
	Group I n = 34	Group II n = 34	<i>p</i>
Gender, n (M/F)	18/16	17/17	0.92
Age, mean (SD)	62.1 (2.9)	60.5 (4.3)	0.80
Group B / C	17/17	17/17	1
<i>Spirometry parameters</i>			
FVC%pred, mean (SD)	79.5 (23.8)	76.5 (12.4)	0.51
FEV ₁ %pred, mean (SD)	65.4 (24.0)	62.9 (15.8)	0.91
FEV ₁ % FVC%pred, mean (SD)	66.1 (13.6)	66.3 (16.5)	0.62

Notes: * $p \leq 0.05$ between-group analysis (Mann–Whitney U test); M: male; F: female; FVC%pred: force vital capacity percent predicted; FEV₁%pred: forced expiratory volume in one second percent predicted; forced expiratory volume in one second as a % of vital capacity percent predicted; SD: standard deviation

Table 2
Means (SD) for group I (n = 34) and group II (n = 34) and statistics of the Mann–Whitney U test for the comparison at baseline

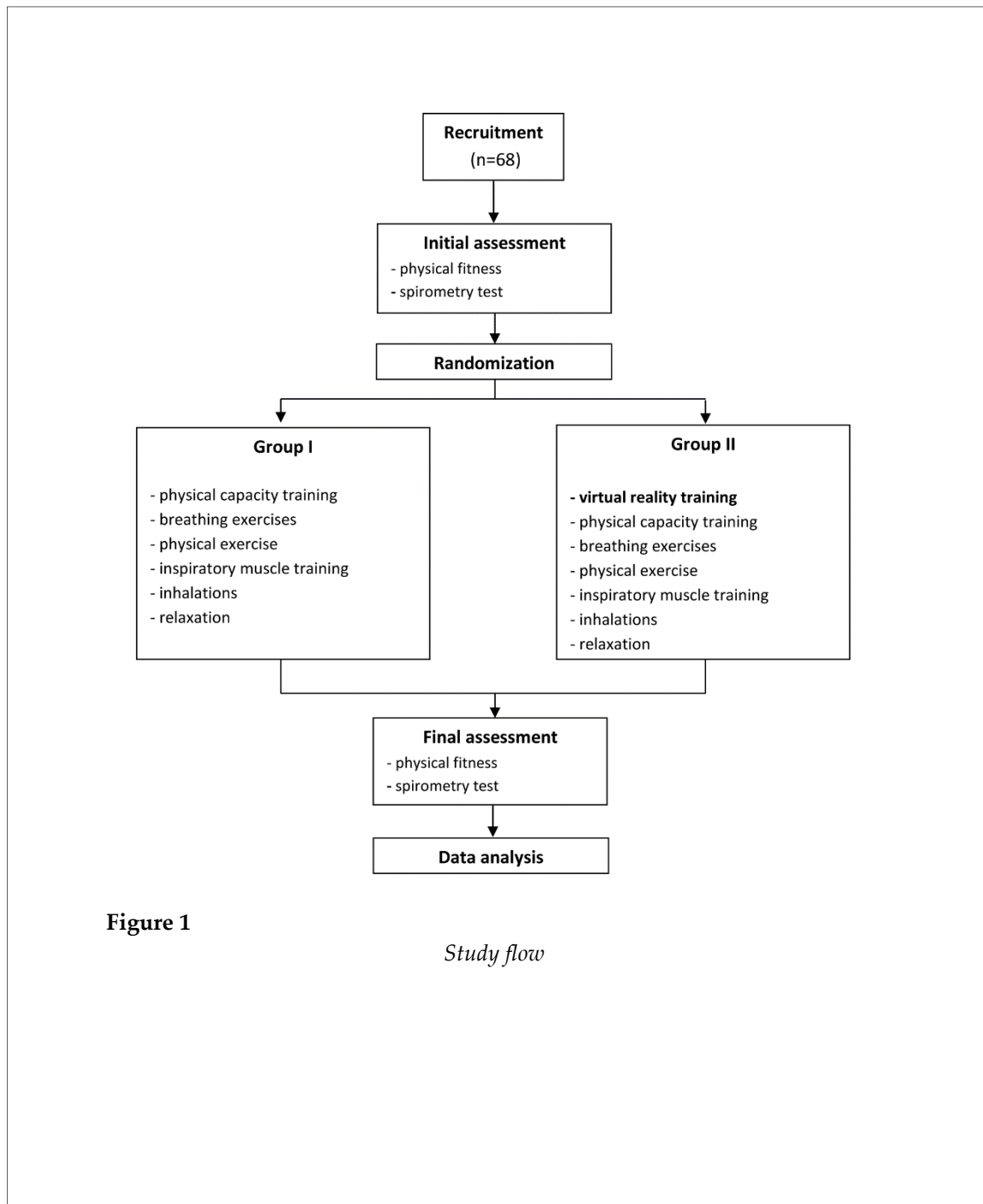
	Mean (SD) group I	Mean (SD) group II	p-value	Cohen's d
Arm Curl (rep.)	19 (2.7)	18.6 (3.1)	0.73	0.39
Chair Stand (rep.)	14.8 (3.2)	14.3 (3.1)	0.75	0
Back Scratch (cm)	-7.6 (7.8)	-6.1 (10.8)	0.30	0.11
Sit and Reach (cm)	0.0 (4.2)	0.7 (10.1)	0.03*	0
Up and Go (s)	6.3 (1.4)	6.0 (0.8)	0.59	0
6MWT (m)	494.9 (38.7)	469.9 (34.3)	0.00*	0.69

Notes: * $p \leq 0.05$ between-group analysis (Mann–Whitney U test); 6MWT; 6-minute walk test

Table 3
Effect of therapies on the Senior Fitness Test

	Mean (SD) group I		Mean (SD) group II	
	pre	post	pre	post
Arm Curl (rep.)	19 (2.7)	20.6 (2.9)*	18.6 (3.1)	21.8 (3.3)*
Chair Stand (rep.)	14.8 (3.2)	15.6 (2.9)*	14.3 (3.1)	16.6 (3.7)*
Back Scratch (cm)	-7.6 (7.8)	-6.8 (7.5)*	-6.1 (10.8)	-4.0 (10.2)*
Sit and Reach (cm)	0.1 (4.3)	1.3 (4.2)*	0.7 (10.1)	3.4 (9.7)*†
Up and Go (s)	6.3 (1.4)	6.0 (1.1)*	6.0 (0.8)	5.3 (0.5)*†
6MWT (m)	494.9 (38.7)	514.7 (33)*	469.9 (34.3)	508.4 (44.3)*

Notes: * $p \leq 0.05$ within-group analysis (Wilcoxon test); † $p \leq 0.05$ between-group analysis (Mann–Whitney U test).



Discussion

For the last couple of years, there has been growth in the implementation of new technologies, including virtual reality and the potential for its application in the rehabilitation process. Stationary rehabilitation reported in this study using a virtual environment that offers one of the few comprehensive approaches to the therapy of COPD patients, has proven successful.

It seems that in this context, it is relevant to consider the application of an inexpensive and widely available virtual game system in the exercise program. VR can offer an important element of therapy under the conditions of stationary rehabilitation both in hospital and at home, and contribute to the decreased duration and amount of hospitalization of COPD patients.

In the present study, a statistically

significant improvement of exercise tolerance was observed in each group. The highest value of this index was seen in group II (8.3%), where the standard PR program was supplemented by training sessions in the virtual environment, whereas in group I that increase was only 4%. We can assume that the longer duration of the rehabilitation program coupled with training in the virtual environment induced improvement of exercise tolerance in the patients participating in the study. The literature provides some data regarding the effect of longer exercise periods on the improvement of exercise tolerance in COPD patients under the conditions of home therapy.

Behnke et al. (2003) analyzed the benefits resulting from the clinical treatment coupled with 18-month home-based rehabilitation in patients in the advanced stages of COPD. This study reports the results based on a program involving walking exercise performed three times per day. In comparison to the control group, of which participants did not follow a specific exercise program (but only guidance regarding health enhancing effects of physical activity), the subjects in the first group significantly improved in terms of the 6-Minute Walking test. In another study, subjects participated in individually tailored and supervised endurance training of the upper limbs and walking. In those patients, significant improvement of exercise tolerance was observed after 12 weeks, combined with better health-related quality of life and reduction of dyspnea. That study also suggests that the home-based rehabilitation program should only supplement hospital treatment (Boxall et al., 2005).

Similar to other studies, our research found improved physical fitness following assessment using the SFT. In both groups the mean values of all variables defining particular tests showed significant improvement. It seems important to note that the improvement of indicators noted throughout the Sit and Reach and Up and Go tests (i.e. involving the improvement of flexibility of the torso region, agility and dynamic balance) recorded in the group following a virtual rehabilitation program using the Kinect environment was statistically higher. The results of our study correspond to findings reported by Aleksander et al. (2008) and Albores et al. (2013). The study by Alexander et al. (2008) reported significant improvement in

physical fitness assessed using the SFT in COPD patients. They conducted a 8-10-week program consisting of 16 exercise sessions performed twice a week. The study by Albores et al. (2013) assessed the exercise capacity, health status, and dyspnea. That experiment used a Nintendo Wii game console to conduct a 12-week home rehabilitation program (one session a day, 5 days per week) in COPD patients. These findings confirm the positive effect of VR exercise on exercise tolerance assessed with the Endurance Shuttle Walk Test (ESWT) coupled with increased endurance and muscle strength (Albores et al., 2013).

Another study on the application of virtual rehabilitation in COPD patients was conducted by LeGear et al. (2014). In the research including 10 patients (mean age 65 ± 8.7 years), the authors showed that the level of physical effort exerted during virtual rehabilitation training was similar to the effort generated during training on a treadmill (LeGear et al., 2014). The study by Wardini et al. (2013) showed significant changes in the frequency of heart contractions, saturation and dyspnea during VR training using the Nintendo Wii system, in patients with COPD. During exercise, significant changes in circulatory and respiratory variables were noted, and the results led to the conclusion that moderate VR exercises were safe and comfortable for patients (Wardini et al., 2013).

The strong point of our study was the inclusion of a control group, which helped to authenticate the results. A limitation of this study, however, was that the sample consisted of patients with moderate COPD. Although very challenging, blinding study researchers and subjects to the experimental condition would be useful. Ultimately, a long-term, randomized, controlled, between-subjects trial with a larger sample size and repeated virtual reality treatments is needed to determine whether there are any long-term benefits to patients who receive systematic, repeated training using VR. Future studies could also determine whether it is possible to use low-cost equipment (console and game) to continue safe home rehabilitation that can help change behavior to increase the level of physical activity of patients with COPD. Moreover, it should be noted that for COPD patients measures for improvement of physical fitness and exercise

tolerance are practically the only ways of treatment due to the irreversible and progressive course of the disease.

It appears that the application of virtual reality in rehabilitation of COPD patients is a feasible option, as demonstrated by the results of this study. The results indicate an improvement of

variables applied to describe exercise tolerance and physical fitness. It can be emphasized here that, to date, there have been no comprehensive studies focused on stationary pulmonary rehabilitation programs in patients with COPD using VR.

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