Manchester Metropolitan University

Jung, Timothy and Moorhouse, Natasha and Shi, Xin and Amin, Farhan (2020)The Evaluation of Pulmonary Rehabilitation in Virtual Reality for Chronic Obstructive Pulmonary Disease Patients. Journal of Medical Internet Research. ISSN 1438-8871

https://e-space.mmu.ac.uk

The Evaluation of Pulmonary Rehabilitation in Virtual Reality for Chronic Obstructive Pulmonary Disease Patients

Timothy Jung, Natasha Moorhouse, Xin Shi, Muhammad Farhan Amin

Table of Contents

The Evaluation of Pulmonary Rehabilitation in Virtual Reality for Chronic Obstructive Pulmonary Disease Patients

Timothy JungMSc, PhD, ; Natasha MoorhouseMSc, ; Xin ShiMSc, PhD, ; Muhammad Farhan Amin

Corresponding Author:
Xin ShiMSc, PhD,
Phone: +447527423967
Email: x.shi@mmu.ac.uk

Abstract

Background: Uptake of traditional pulmonary rehabilitation classes from Chronic Obstructive Pulmonary Disease (COPD) patients is poor due to personal factors preventing accessibility to the venue. Therefore, there is a need for innovative methods of pulmonary rehabilitation and Virtual Reality (VR) could be the promising technology for COPD patients to access services remotely.

Objective: This study aims to investigate whether VR improves COPD patient's compliance with pulmonary rehabilitation, particularly vulnerable patient group (MRC four or five), and whether VR provides a credible alternative to traditional pulmonary rehabilitation programmes.

Methods: Eight-week patient trial using an innovative VR pulmonary rehabilitation programme. Purposive sample of ten COPD patients graded MRC four or five registered at a selected healthcare centre and a hospital in Cumbria, UK. Qualitative (focus groups and interviews) data were collected and to further support the qualitative findings, quantitative data (self-report patient surveys) were also gathered before and after the eight-week trial. The five self-report surveys included the Patient Activation Measure (PAM), Generalized Anxiety Disorder (GAD-7), Patient Health Questionnaire (PHQ-9), Short Physical Performance Battery (SPPB), and the Edmonton Frail Scale (EFS).

Results: Using thematic analysis for the qualitative data, eleven themes emerged specific to delivering pulmonary rehabilitation using VR. The quantitative data further supports the qualitative findings by revealing significant improvements in all physical measures.

Conclusions: Overall, this study demonstrates how remotely supervised VR-based pulmonary rehabilitation could help to overcome current issues and limitations associated with providing this service to COPD patients at scale.

Preprint Settings

1) Would you like to publish your submitted manuscript as preprint?

✔ **Please make my preprint PDF available to anyone at any time (recommended).**
   Please make my preprint PDF available only to logged-in users; I understand that my title and abstract will remain visible to all users.
   Only make the preprint title and abstract visible.
   No, I do not wish to publish my submitted manuscript as a preprint.

2) If accepted for publication in a JMIR journal, would you like the PDF to be visible to the public?

✔ **Yes, please make my accepted manuscript PDF available to anyone at any time (Recommended).**
   Yes, but please make my accepted manuscript PDF available only to logged-in users; I understand that the title and abstract will remain v
   Yes, but only make the title and abstract visible (see Important note, above). I understand that if I later pay to participate in <a href="http

Original Manuscript

The Evaluation of Pulmonary Rehabilitation in Virtual Reality for Chronic Obstructive Pulmonary Disease Patients

Abstract

Background: Uptake of traditional pulmonary rehabilitation classes from Chronic Obstructive Pulmonary Disease (COPD) patients is poor due to personal factors preventing accessibility to the venue. Therefore, there is a need for innovative methods of pulmonary rehabilitation and Virtual Reality (VR) could be the promising technology for COPD patients to access services remotely.

Objectives: This study aims to investigate whether VR improves COPD patient's compliance with pulmonary rehabilitation, particularly vulnerable patient group (MRC four or five), and whether VR provides a credible alternative to traditional pulmonary rehabilitation programmes.

Methods: Eight-week patient trial using an innovative VR pulmonary rehabilitation programme. Purposive sample of ten COPD patients graded MRC four or five registered at a selected healthcare centre and a hospital in Cumbria, UK. Qualitative (focus groups and interviews) data were collected and to further support the qualitative findings, quantitative data (self-report patient surveys) were also gathered before and after the eight-week trial. The five self-report surveys included the Patient Activation Measure (PAM), Generalized Anxiety Disorder (GAD-7), Patient Health Questionnaire (PHQ-9), Short Physical Performance Battery (SPPB), and the Edmonton Frail Scale (EFS).

Results: Using thematic analysis for the qualitative data, eleven themes emerged specific to delivering pulmonary rehabilitation using VR. The quantitative data further supports the qualitative findings by revealing significant improvements in all physical measures.

Conclusion: Overall, this study demonstrates how remotely supervised VR-based pulmonary rehabilitation could help to overcome current issues and limitations associated with providing this service to COPD patients at scale.

What is already known on this topic?
- COPD is a global public health burden that needs to be addressed to reduce the substantial cost associated with the disease and improve patient's quality of life.
- Remotely supervised VR could complement conventional therapy, which has demonstrated poor uptake due to patients' personal barriers.
- Limited research has investigated the benefits and outcomes of VR for pulmonary rehabilitation, which leaves an important area of research requiring further investigation.

What this study adds
- VR provides opportunity for an interactive and visually stimulating approach for use in clinical treatment and could provide pulmonary rehabilitation to those COPD patients that cannot easily access traditional rehabilitation methods.
- This study provides a significant contribution to healthcare research investigating the benefits of implementing digital technologies to improve rehabilitation, with particular contribution to pulmonary rehabilitation research.
- Important practical implications for the healthcare industry and medical practitioners on the benefits of VR for pulmonary rehabilitation are offered.

Introduction

Pulmonary rehabilitation is a non-pharmacological intervention designed for patients with Chronic Obstructive Pulmonary Disease (COPD) that involves supervised exercise training, disease education, and behavioural interventions [1]. It is now one of the most effective treatments in significantly improving symptoms of dyspnoea (i.e. breathlessness) [2, 3, 4], exercise capacity,

improved quality of life [2, 4, 5, 6], and anxiety and depression in COPD patients [1, 7]. However, uptake is poor and completion rates are low [1, 7, 8]. Patients that qualify for pulmonary rehabilitation are those graded three or above on the Medical Research Council (MRC) breathlessness scale, which is a validated measure on disease severity used in many scientific studies across the world, given that this particular group are at high risk of exacerbation and hospital admission [9, 10, 11]. However, patients have difficulty attending classes due to lack of transport and geographic distance to a programme, fatigue, motivation, inconvenience, disruption caused to daily activities, as well as the quality of the healthcare professionals' conversation with patients about pulmonary rehabilitation [12, 13]. Depression, burden of illness, low awareness of rehabilitation, and knowledge of, and disbelief in, the beneficial rehabilitation outcomes are also considered barriers to patient uptake [14, 15, 16]. Therefore, researchers and practitioners are searching for innovative methods to deliver more engaging rehabilitation for patients with a variety of long-term conditions that affect physical activity.

More recently, there has been an increase in research focusing on the effects of Virtual Reality (VR) for patients with chronic diseases that inhibit physical activity. For example, studies focusing on individuals with Parkinson disease have investigated the effects of gait training with VR [17], while others have compared home-based VR balance training with conventional home-based balance training [18]. The physical and psychological benefits of VR for stroke patients has also been explored [19, 20]. However, despite the extant research in this area, studies investigating VR for physical training rehabilitation programmes have demonstrated varying results, which has meant that researchers and practitioners are unsure about its true impact [21, 22]. The need for innovative methods of pulmonary rehabilitation is evident and VR could be the promising technology providing COPD patients with a convenient and remotely accessible pulmonary rehabilitation programme. COPD places a significant financial burden on individuals and societies worldwide and is a global public health burden that needs to be addressed to reduce the substantial cost associated with the disease and improve patient's quality of life [23, 24]. Remotely supervised VR could complement conventional therapy [25], which has demonstrated poor uptake due to patients' personal barriers [8]. However, so far, to the best of authors knowledge, limited research has investigated the benefits and outcomes of VR for pulmonary rehabilitation, which leaves an important area of research requiring further investigation. To address this gap, this study aims to investigate whether VR improves COPD patient's compliance with pulmonary rehabilitation, with particular focus on the vulnerable patient group (MRC four or five), and whether this technology provides a credible alternative to traditional pulmonary rehabilitation programmes. The results of this study provide significant theoretical contributions to the field of health care research, while providing important implications for health practitioners.

Literature Review

Technology-facilitated methods of pulmonary rehabilitation

COPD is characterised by progressive airflow obstruction and cannot be fully reversed [26]. COPD patients find difficulty with physical activity and often have episodes of exacerbation including breathlessness and coughing, which provokes anxiety and episodes of panic leading to an overall decline in everyday function and overall quality of life [26, 27, 28, 29]. The psychological consequences of COPD include symptoms of depression, general anxiety [30, 31, 32, 33, 34, 35], psychological repercussions including fear, panic, loss of confidence and social isolation [36, 37], which have important implications for the adoption and maintenance of healthy behaviours [38]. In turn, this restricts patients' ability to perform daily activities and due to fear of dyspnoea, they often avoid physical activity and social events, which may contribute to increased likelihood of depression

in elderly COPD patients [30, 36, 37]. However, the increasingly sedentary lifestyle leads to muscle weakness, further reductions in physical activity, reduced exercise capacity, and even more severe symptoms [39, 40]. The MRC breathlessness scale measures perceived respiratory disability and is widely used to describe patient cohorts and stratify them for interventions such as pulmonary rehabilitation in COPD [29, 40]. More specifically, patients graded MRC three or above are considered eligible for pulmonary rehabilitation services [9].

Rehabilitation facilitated by information and communication technologies (ICTs) is known as telerehabilitation [41, 42]. Over the last few years, there has been an increase in telerehabilitation applications due to the development of new technologies [43]. In comparison to traditional inpatient or person-to-person rehabilitation, telerehabilitation allows for remote communication and is therefore more cost-effective for both health care providers and patients [43]. Some examples include in-home videoconferencing [44, 45], mobile phone-based exercises programmes [46], web-based self-monitoring [47, 48, 49], and more recently socially assistive robots [50] and VR. Studies have suggested that telerehabilitation is suited to older people given that it could improve quality of life, allow for more independent living, is more convenient in terms of not having to travel to appointments, and enables cost-effective services [51, 52, 53, 54]. However, despite the growing evidence-based research demonstrating positive clinical outcomes and increasing telehealth utilisation, patients are faced with equipment set-up related difficulties, limited scope of exercise, and connectivity [55].

Although completion of pulmonary rehabilitation is associated with improved outcomes including reduced subsequent hospital admission rates and better survival [10], uptake and completion rates remain poor due to personal barriers associated with time, costs, fatigue, motivation, and inconvenience [8]. COPD is the third leading cause of death worldwide and in 2016 the Global Burden of Disease study reported a prevalence of 251 million global cases of COPD that year [56, 57]. Research has indicated that COPD affects at least 320 million people and has a global economic cost of US $2.1 trillion [58, 59]. Significant healthcare costs are associated with treatment of exacerbations including hospital visits, and for medication costs for maintenance therapy and outpatient treatment [24, 29]. Over the past few years, GPs have been encouraged to explore new ways of improving COPD management and reduce hospital admissions [60]. A deeper understanding of the barriers associated with COPD patient's acceptance and uptake of pulmonary rehabilitation could reveal new methods to improve its uptake [10, 60], which would reduce the considerable healthcare burden of COPD on patient's quality of life and the health economy. In addition, self-management interventions could lead to a reduction in COPD specific health costs from reducing hospital admissions [61, 62, 63]. Therefore, researchers and practitioners have sought innovative methods to create more exciting rehabilitation programmes for patients such as VR, which is said to increase their excitement and interest, and excitement often leads to increased motivation to complete the rehabilitation programme [21, 64, 65, 66].

The use of Virtual Reality for physical training and rehabilitation

With recent technical advancements in VR, innovative approaches to improve traditional physical therapy and rehabilitation programmes can be explored [21, 67, 68]. VR can be defined as a computer-assisted technology that provides the user with an immersive, interactive, and multi-sensory experience in a three-dimensional virtual environment. The most cutting-edge hardware to facilitate VR is the Head Mounted Display (HMD). Patients can control digital recreations of their physical bodies (i.e. avatars) to perform practice behaviours in the virtual environment [21]. Several studies have demonstrated that VR rehabilitation programmes may develop physical outcomes [69,

70, 71, 72], outperform traditional rehabilitation programmes [17, 73, 74], and provide greater benefits in walking speed, balance, and mobility [75]. Many VR programmes are designed with tasks that challenge the user, and well-designed VR rehabilitation programmes could lead to improvements in cognitive, motor, and social aspects [76, 77]. Given that VR can be accessed without supervision, increased dosage of therapy can be provided without increasing staffing levels [77]. Remotely supervised VR interventions could complement conventional therapy programmes and would be particularly suited in situations where cost savings are mandatory and/or when transport to the clinic is difficult for the patient [25]. From patients' perspective, VR environments for rehabilitation are naturally considered to be more exciting and enjoyable than traditional rehabilitation methods, which means patients exert more effort and are more motivated to conduct VR rehabilitation in comparison [21, 64, 78, 79]. As a result, patients benefit from greater autonomy and mobility in conducting their daily activities [17]. However, few studies have investigated whether increased motivation explicitly leads to positive rehabilitation outcomes [21]. As VR is still a fairly recent addition to delivering physical therapy and rehabilitation, there is still uncertainty in the benefits, despite the emerging research in this area [22, 80]. However, as VR technology becomes more accessible and affordable, it will likely become more widely used in clinical rehabilitation settings [80, 81, 82]. Therefore, additional trials are required to evaluate the efficacy and determine the acceptability and feasibility of VR in order to guide future design and implementation of these systems into clinical practice [22, 42].

Methods

Study design

Patients participated in an eight-week trial using the "PR in VR" (i.e. Pulmonary Rehabilitation in Virtual Reality) programme and both qualitative and quantitative data were collected. During the trial, each patient was provided with a Pico Goblin VR headset embedded with the PR in VR application and a small probe Nonin 3150 at their home for an eight-week period. Patients wore the probe while exercising in order to measure their Heart Rate (HR) and Oxygen saturation levels (displayed as %). Pulse Oximeter data was used by clinical staff to remotely measure patients' Oxygen saturation and HR while patients were exercising. Clinical staff used a web-based dashboard to observe this data remotely during the rehabilitation session. PR in VR was designed to enable patients to perform various exercises in their home as displayed in the VR environment and consisted of eight separate modules. It was anticipated that patients would spend at least 20 minutes per day using the VR rehabilitation programme and complete one module per day during the eight-week period. Specifically, the application was divided into two subgroups 1) education and 2) rehabilitation. Each subgroup has further modules accessed from within the application. The education section contains HD videos with cinematic effects (visuals and audio) to increase patients' retention. The rehabilitation section (modules 5-7) consists of physical exercises led by a virtual instructor in the form of a 3D avatar. The physical exercises were drawn from the traditional pulmonary rehabilitation programme and tailored to be suitable for completing while wearing the VR headset (e.g. seated exercises). The final module (module eight) is a summary of the PR in VR programme. The application is designed to send this data in real-time to the server, and patients can monitor this data while exercising as it is displayed in the corner of the VR display screen.

Participants

The sample of ten elderly COPD patients (graded at MRC four or five) aged between 63 and 75 years old were recruited in the UK. Six patients from a health practice in South Cumbria and four patients from a general hospital in West Cumbria, where recruited by the local physiotherapist in

each location. Ethical approval was granted by Manchester Metropolitan University's Ethical Committee prior to data collection. Patients graded MRC four and five were provided the option to trial the PR in VR programme or wait one year to attend the traditional rehabilitation classes at the local rehabilitation centre. All patients invited to take part in the trial agreed, however, due to the limited number of devices, only those patients that confirmed their interest first where recruited. There are six out of ten male patients. Table 1 portrays the patients' demographic profile and entails the coding (P1-P10) (P = Patient) used for the qualitative analysis. The average ages of female patients in this study is 70 and the female participants are three years younger in average.

Table 1. Patients demographic profile

Patient No.	Age	Gender
P1	75	M
P2	68	M
P3	69	M
P4	73	F
P5	62	F
P6	71	M
P7	76	M
P8	69	F
P9	63	F
P10	63	M

Data collection

Prior to using PR in VR, patients' functional ability was assessed and together with the physiotherapist they were each asked to set a short-term goal (e.g. increase walking distance without breathlessness) and a long-term goal (e.g. feeling confident to leave the house on his/her). Patients conducted five self-report surveys before and after using PR in VR.

In health and well-being research, qualitative methods are widely used because they provide insights into the perceptions and experiences of patients and health care professionals [83]. During June 2018, two focus groups and six one-to-one interviews were conducted in Cumbria. Each focus group was led by two researchers, one physiotherapist, and one healthcare assistant in each location. The first focus group, consisting of three COPD patients, was conducted at a health practice in South Cumbria and lasted approximately 75 minutes. Later, four one-to-one interviews were conducted by the physiotherapist in the same location and lasted between eleven and 25 minutes each (interview 1 = 12 minutes, interview 2 = 11 minutes, interview 3 = 15 minutes, interview 4 = 23 minutes). The second focus group, consisting of two COPD patients, took place at a general hospital in West Cumbria and lasted approximately 45 minutes. Then, the physiotherapist and healthcare assistant gathered two more one-to-one interviews at the same location, which lasted 16 minutes (interview 5) and 15 minutes (interview 6). Focus groups and interviews were carried out at the end of each COPD patient's eight-week VR-based rehabilitation programme. During the focus groups and interviews, the questions aimed to explore how patients benefit from the PR in VR programme, how satisfied they are with using it, and identify the areas requiring further development. Drawing on the integrated educational aspect, questions explored the effectiveness and benefits of immersive training in this specific context, and further explored the usability of the VR device and application, as well as patients' intention to use PR in VR in the future.

Data analysis

The qualitative data were transcribed verbatimly before being analysed using thematic analysis, which is a method used to identify patterns (i.e. themes) within a data set through a rigorous process of identification, analysis, organisation, description, and reporting of those themes [84]. Thematic analysis is widely used in healthcare research [55, 85, 86, 87], and was considered most appropriate for this study because it is suited to questions related to people's experiences, or views and perceptions, such as in this study.

In addition, all patients completed the five self-report surveys before and after the trial to ensure a comparison could be made between each of the patients' pre and post test scores. This was important to determine whether he/she showed improvements after using the PR in VR programme. An analysis of the pre and post scores was conducted using Excel.

Results

The purpose of focus groups and interviews was to explore how patients benefit from the PR in VR programme, how satisfied they are with using it, and identify the areas requiring further development. In addition, the effectiveness and benefits of immersive learning in this specific context, the usability of the VR device and application, and patients' intention to use PR in VR in the future was explored. From the analysis, eleven themes emerged and are presented in Table 2. The themes are discussed in further detail below and provide support with direct quotations from the qualitative data collection.

Table 2. Themes and description of each theme

Themes	Description
Increased compliance	Significant increase in patients' compliance with pulmonary rehabilitation (i.e. conducting their exercises).
Increased engagement	Increased engagement in pulmonary rehabilitation when using VR due to enjoyment.
Physical improvements	Significant patients' physical improvements (i.e. strength, mobility, and flexibility).
Improved psychological well-being	Patients' psychological well-being has significantly improved.
Improved Health-related Quality of Life (HRQoL)	Patients feel healthier and fitter (i.e. they can confidently leave the house and socialise more than before).
Increased confidence	Significant improvements in confidence in terms of patients managing their condition, conducting daily activities, and physical exercises.
Patient satisfaction	Patients are satisfied with completing the PR in VR programme and achieving their short-term and long-term goals.
Increased feeling of security	Patients feel more secure, reassured, and confident to exercise knowing their physiological data is being remotely supervised.
Effective immersive learning	Effectiveness of immersive learning for COPD patients was demonstrated.
Personalised programmes	A recommendation is to provide programmes tailored to suit various levels of COPD.

Needs of technological improvements	Need for technological improvements of both the device (e.g. a more lightweight headset) and content of the application (e.g. additional functions to control the pace and standing up exercises) to improve patients experience.

Increased compliance

The findings demonstrate that PR in VR significantly increases patients' (P1-P10) compliance with the frequency and consistency of conducting their exercises. For example, patients had difficulty attending the rehabilitation centre due to difficulty incorporating it with their personal commitments.

> P9: "I couldn't complete traditional rehabilitation. There was always something cropped up".

In comparison, using PR in VR remotely was "easier" (P9) and "pleasurable rather than chore-like" (P9) given that it could be integrated into their daily routine on a more flexible basis. For COPD patients, this is an important factor because several patients (P1-P10) mentioned that some days they are not feeling well enough, physically and/or mentally, to travel to the rehabilitation centre. Therefore, being able to access pulmonary rehabilitation anywhere at any time is highly beneficial and attractive for this target group.

> P9: 'VR is more akin to my needs. I did not feel like traditional classes where doing anything for me".
> P2: "I prefer to do it at home, partly because of getting to the venue".

Increased engagement

Compared with prior pulmonary rehabilitation methods, PR in VR increased engagement for all participants (P1-P10) because it is more enjoyable, and more importantly, having the 3D avatar gave the experience a social aspect. Therefore, patients were more disciplined with PR in VR than they have been with previous methods such as the booklet.

> P8: "I was amazed how I actually looked forward to doing [PR in VR] and getting on it and seeing the chap and doing [the exercises] with him".
> P9: "You discipline yourself to use it. If it's not there, then I don't think I would. You just don't do them [exercises using the booklet]…but [with VR] the guy is there and he's talking to you, and you feel as though you are with the two people, it's just the feeling it gives you".

Patients are more engaged with PR in VR because they feel more comfortable to conduct their exercises in their home environment at their own leisure.

> P8: "Because it was at home, I think I did it more. Whereas I would have been ringing the class to tell them I cannot make it because I don't feel well enough".

Physical improvements

Participants (P1, P3, P4, P5, P7-P10) demonstrated physical improvements including increased strength, increased mobility, and increased flexibility.

> P8: "I know certainly my legs are stronger. I can feel that even just getting up off the chair".
> P4: "I can't walk to the car without having to stop usually. But when I am not doing the exercises, I could walk to the car without having to stop"
> P1: "I am a lot more flexible and without the pain!".

Several exercises in the PR in VR programme focused on developing strength in the thigh muscles, which subsequently improved patients' cardiovascular fitness therefore enabling them to walk further (P1-P10). In addition, patients reported increased strength in their upper body, which resulted in them feeling less breathless and with a much quicker recovery time when breathlessness did occur. As a result of the consistent physical activity, as opposed to minimal daily movement, patients feel healthier both physically and mentally.

> P9: "After using VR, I am less breathless…my recovery time is much quicker".
> P1: "I do feel healthier in myself…I feel a lot better with myself, with the movement, physically. I used to just sit in my chair and do nothing".

Improved psychological well-being

In relation to the previous theme (physical improvements), patients' psychological well-being significantly improved.

> P1: "When I've finished the Thai Chi I do feel physically and mentally relieved".

Recommendation to others in their situation was confirmed by all patients (P1-P10), largely due to the psychological benefits, which are particularly important for COPD patients given the associated mental health problems (e.g. depression) often experienced from the initial diagnosis to adapting to living with COPD. In line with this, motivation played a key factor in patients' enthusiasm to continue with PR in VR. Overall, this could assist with overcoming mental health problems and improve their general psychological well-being.

> P4: "Motivation is my main reason to continue. Because I get depressed really easily".
> P3: "It gets me motivated and I'm in the [wheel]chair a lot because of my health so doing the exercises does motivate me but sometimes I don't like being honest about it, but I have to mentally build up to do it because of the way I am feeling. But yes, I would recommend it".

Improved Health Related QoL

Improvements with physical and psychological well-being are positively associated with HRQoL as demonstrated by all participants (P1-P10). Conducting daily activities is more enjoyable than before and patients are more sociable.

> P9: "It has made my daily activities easier…I am more comfortable with what I do".
> P7: "I am getting out and about now".

For example, P4 had not left the house in almost two months prior to starting PR in VR. In addition, patients feel happier because they have been able to spend more quality time with friends and family.

> P4: "From sitting on a sofa I had been able to go with my husband for a coffee, to go out in the car, and I had not done any of that for 7 weeks. It had got me to the stage again where I felt I could go out and go shopping with the trolley. I have done none of that for about 2 months".
> P7: "Going out every day has made a difference; I have been seeing my friends".

Increased confidence

Most of the patients (P1-P5, P7-P10) reported significant improvements in confidence in terms of managing their condition, conducting daily activities, participating in social activities, and managing their breathing.

> P7: "I can get upstairs in one go now".
> P4: "It builds my confidence up because I can go out more".
> P9: "It has given me more confidence in breathing along with what I am doing".

In reflecting on this, patients discussed how they had lost motivation and confidence in their ability to manage tasks themselves without the support of their partners and several had "given up" (P3, P4, P7- P10). In turn, patients have gained back more control in their life.

> P8: "I think I had given up. I decided that the illness had gone so far that I was not going to get better, I was not going to get out again, or enjoy life. It has completely reassured me that way and given me the energy to get going again".
>
> P7: "Possibly it was a mental thing. I felt confident enough. I started filling my own flasks".

Patient satisfaction

Successful completion of their exercises within a given day using PR in VR is positively associated with patient satisfaction (P1-P10). Noticing improvements with their physical wellness enabled patients to feel satisfied and confirmed the benefits associated with following the PR in VR programme.

> P8: "What I enjoyed most was knowing that I could get through the exercises. Knowing that my oxygen was not dropping. It was a real achievement for me. I was used to going to the toilet and coming back and having to catch my breath. All of a sudden, I could do these exercises and after a few times I was still breathing normal".

Given that PR in VR is self-managed and remotely supervised, patients' self-motivation played a critical factor in their consistency with exercising and subsequent self-satisfaction.

> P4: "I feel satisfied that I motivated myself to do it. It did help me to do it. I feel satisfied when I sit down and think that's me done for tonight".

Increased feeling of security

A primary concern for patients was experiencing exasperation during exercises when at home alone. In comparison to previous methods, PR in VR is advantageous because it allows for remote supervision, meaning that patients' physiological data (i.e. HR and oxygen level) is continuously tracked and monitored by health practitioners. Therefore, this function improved patients experience because they felt more secure (P9), confident (P7 and P9), and reassured (P8) knowing they are being monitored while exercising in real time should exacerbation occur.

> P8: "The minute I am getting out of breath [at home] I go into panic".
>
> P9: "It has given me more confidence in breathing along with what I am doing".
>
> P8: "It reassured me being able to see my oxygen level and heart rate while I was exercising. I feel it has increased my confidence".

Further, this function assisted patients with better managing their condition and to avoid overexerting themselves into exasperation.

> P8: "[PR in VR] has improved my breath…in the VR it shows the oxygen go up and back down again, it gave me that back again where I could settle myself down".

Effective immersive learning

PR in VR provides patients with information on COPD with an aim to help them better manage their condition. The findings demonstrated the effectiveness of immersive learning for COPD patients because it educated them on the disease, which some participants had never had explained to them. For instance, P1 found the learning aspect useful and *"very informative to find out what is actually happening"*. During the focus groups, P1 could reiterate what he had learned from the programme five weeks prior.

> P1: "That's the first time I have seen on screen what emphysema actually is".

The PR in VR programme has increased patient's awareness on their breathing techniques (P1, P3, P8) and the variety of exercises required to target various muscles and support their overall health and well-being. The findings further support the effectiveness of immersive learning, specifically using VR for COPD patients.

> *P8: "He says breath out when you do the exertion, I was not doing that before…it has improved my breath…the voice over was helpful and reassuring".*
> *P3: "I think it's a good idea. It reminds you that you've got to do different exercises to target different muscles".*

Personalised programmes

Recommendations to improve patients experience of PR in VR were provided. Patients (P1-P6, P8, P10) suggested various levels of exercises (i.e. harder set of exercises and easier set of exercises) to suit the many levels of COPD patients could improve the programme. More specifically, patients (P2, P5, P10) explained how the first two to three levels were "too easy" (P5), slow paced (P5), and too long (P10), and were eager to push onto more "severe" modules (P10). Therefore, those patients require more advanced exercises to ensure they are constantly being challenged. On the contrary, the more advanced exercises were too challenging for other patients (P1, P3, P4, P5) on the first attempt, and require repetition given that they might not have exercised in prolonged period of time prior to using PR in VR. Indeed, those patients enjoyed the flexibility of being able to move back and forth throughout the modules depending on their well-being at that time.

> *P4: "It is beneficial to have the different levels so I can drop down depending how I feel each day".*

Furthermore, it was suggested that a variety of exercises at the same difficulty level would retain engagement.

> *P5: "I would like two or more routines in each module instead of doing the same thing all the time. For longer than six weeks it would become boring".*

Needs of technological improvements

Furthermore, in order to improve patients experience of PR in VR, technological improvements of both the device and application are required (P1-P10). For instance, the main technical issue within the application whereby the camera moves to the right and takes several seconds to re-centre was a recurrent topic of conversation. Hence, improved graphics would enhance the experience but were considered a minor factor in the overall rehabilitation experience that could easily be solved.

> *P5: "The whole thing was excellent it really was except for the glitches but I am sure that can be overcome".*

Suggestions for additional functions include a fast-forward and pause button (P1-P5) to allow patients to have more control over the programme and pause it while they recover.

> *P1: "If you could pause it when you know that you're going to get out of breath".*

All patients (P1-P10) found the headset easy to use, however, some required it to be more lightweight (P4, P5 and P9). Regarding the content, some patients (P1-P5) would enjoy standing-up exercises.

In addition to focus groups and interviews, quantitative data were collected, and the findings further support the qualitative findings. Table 3 presents the outcome measure results. The average for each of the five surveys was calculated based on the patient data gathered before and after the VR rehabilitation programme. As it can be seen, the findings demonstrate an improvement for all outcome measures from the pre and post results. The CRQ results indicate that patients have

improved dyspnoea, fatigue and emotional function post-VR. Female participants collectively showed more of an improvement in both dyspnoea and emotional function than male participants. The PHQ-9 and GAD-7 demonstrate that a substantial proportion of patients have reduced feelings of depression and anxiety, respectively, which further supports the theme of improvements in patients' psychological well-being. The results of the EFS and the SPBB are positively associated with patients' physical improvements including strength, mobility, and flexibility. Finally, the PAM results demonstrate patient's progression with knowledge, skills and confidence in self-managing their condition post-VR.

Table 3. Outcome measure results pre and post-VR

Outcome Measures	Pre-VR Results (Average)	Post-VR Results (Average)
SPPB	6.78	8.43
CRQ – Dyspnoea	2.22	2.96
CRQ – Fatigue	3.11	3.27
CRQ – Emotional	3.85	4.36
CRQ – Mastery	3.83	3.83
PAM	60.84	63.46
EFS	6.56	5.38
PHQ -9	8.44	6.11
GAD - 7	5.78	4.22

Discussion and conclusion

The aim of this study is to assess the benefits and outcomes of VR as an innovative method for pulmonary rehabilitation in two aspects. Firstly, the study aimed to investigate whether VR improves compliance with pulmonary rehabilitation with COPD patients, particularly vulnerable patient group (MRC four or five). Finding innovative pulmonary rehabilitation treatment methods that engage this particular patient group is vital given the severity of the disease that impacts on HRQoL and the barriers associated with attending traditional rehabilitation classes [12, 13, 14, 15]. This study demonstrates that PR in VR significantly increases patients' compliance with pulmonary rehabilitation compared with traditional methods mainly because of the flexibility to exercise at any time of day and location, not restricted to home or clinic-based scenarios, which is more accommodating for their daily psychological and physical well-being [88]. The second research question was to investigate whether VR provides a credible alternative to traditional pulmonary rehabilitation. Thematic analysis revealed nine themes illustrating the benefits associated with PR in VR compared with traditional methods. Patients demonstrated significant improvements with physical ability and psychological well-being because of their consistency with exercises, thus, improving patients HRQoL. These findings are consistent with both the quantitative results in this study and previous research investigating the benefits of VR for other chronic diseases [17, 64, 69,

70, 71, 73, 74, 78], while providing evidence specific to COPD patients. Because of its remote accessibility, PR in VR provides a solution to overcome the associated barriers with attending traditional rehabilitation classes (i.e. transport and travel, fatigue, motivation, inconvenience, burden of illness, disruption caused to daily activities, low awareness of rehabilitation, and knowledge of, and disbelief in, the beneficial rehabilitation outcomes) [12, 13, 14, 15]. Indeed, patients feel secure and confident enough to exercise without face-to-face supervision because health practitioners can remotely monitor their physiological performance data when using PR in VR. Pulmonary rehabilitation is delivered to a low proportion of the population despite its demonstrated benefits for COPD patients [8]. However, PR in VR can be deployed at scale, which provides a solution to the reoccurring issue of too-long a waiting list for rehabilitation classes [10] and allows health practitioners to performance measure delivering Digital Precision Medicine. Overall, this study demonstrates how remotely supervised VR based pulmonary rehabilitation can help to overcome current issues and limitations associated with providing this service to COPD patients at scale. In comparison to previous methods, VR could provide a more cost-effective solution for the health treatment to deliver pulmonary rehabilitation to a vast majority of this patient group nationwide.

Contribution, Implications, and Future Research

Previously, studies have investigated the benefits of using VR for rehabilitation for long-term conditions [17, 18, 89]. However, its benefits for self-managed and remotely supervised pulmonary rehabilitation remain unexplored, and to the best of the researchers' knowledge this study is one of the first to provide empirical evidence using qualitative data that is further supported by quantitative results. Therefore, this study contributes important findings demonstrating that PR in VR represents an effective form of self-managed and remotely supervised pulmonary rehabilitation that can be delivered at scale. Overall, this study provides a significant contribution to healthcare research investigating the benefits of implementing digital technologies to improve rehabilitation, with particular contribution to pulmonary rehabilitation research. Moreover, this study provides important practical implications for the healthcare industry and medical practitioners on the benefits of VR for pulmonary rehabilitation. PR in VR is an innovative application distinctive from previous self-managed rehabilitation methods because it allows health practitioners to supervise COPD patients remotely and at scale, and to performance measure delivering Digital Precision Medicine. The current investigation offers proof of concept that the PR in VR intervention can be used for elderly COPD patients. With evidence, this alternative intervention platform provides an interactive and visually stimulating approach for use in clinical treatment and could provide pulmonary rehabilitation to those COPD patients that cannot easily access traditional rehabilitation methods.

This study has several limitations that could be mitigated by further research. The first limitation pertains to the limited sample size; however, this is common in other exploratory studies investigating VR for rehabilitation [18, 89]. This study employed ten COPD patients aged between 63 and 75 years old from the UK. Although small sample sizes can provide important initial inferences about a topic, they can provide few firm conclusions [21]. However, because this is the first study investigating VR for pulmonary rehabilitation, a small sample size offers a promising pilot data as a first phase trial. Furthermore, COPD in the UK is common among people aged 40 years and over [90], therefore, it is important that future studies employ a larger sample covering the majority proportion of the respective age group.

References

1. Hayton C, Clark A, Olive S, Browne P, Galey P, Knights E, Staunton L, Jones A, Coombes E,

Wilson AM. Barriers to pulmonary rehabilitation: Characteristics that predict patient attendance and adherence. *Respiratory Medicine 2013,* 107:401-407. PMID: 23261311

2. McCarthy B, Casey D, Devane D, Murphy K, Murphy E, Lacasse Y. Pulmonary rehabilitation for chronic obstructive pulmonary disease. *Cochrane Database Syst Rev,* 23(2). PMID: 25705944

3. Sundararajan L, Balami J, Packham S. Effectiveness of outpatient pulmonary rehabilitation in elderly patients with chronic obstructive pulmonary disease. *Journal of Cardiopulmonary Rehabilitation Prevention 2010,* 31:121-125. PMID: 19952774

4. Norweg AM, Whiteson J, Malgady R, Mola A, Rey M. The effectiveness of different combinations of pulmonary rehabilitation program components: A randomised trial. *Chest 2005,* 128:663-672. PMID: 16100152

5. Lacasse Y, Martin S, Lasserson TJ, Goldstein RS. Meta-analysis of respiratory rehabilitation in chronic obstructive pulmonary disease. A Cochrane systematic review. *Europa Medicophysica 2007,* 43(4):475-485. PMID: 18084170

6. Ries AI, Bauldoff GS, Carlin BW, Casaburi R, Emery CF, Mahler DA, Make B, Rochester CL, Zuwallack R, Herrerias C. Pulmonary Rehabilitation: Joint ACCP/AACVPR Evidence-Based Clinical Practice Guidelines. *Chest 2007,* 131:4-42. PMID: 17494825

7. Hogg L, Garrod R, Thornton H, McDonnell L, Bellas H, White P. Effectiveness, attendance, and completion of an integrated system-wide pulmonary rehabilitation service for COPD: Prospective observational study. *COPD Journal of Chronic Obstructive Pulmonary Disease 2012,* 9(5):546-554. PMID: 23030586

8. Seidman Z, McNamara R, Wootton S, Leung R, Spencer L, Dale M, Dennis S, McKeough Z. People attending pulmonary rehabilitation demonstrate a substantial engagement with technology and willingness to use telerehabilitation: a survey. *Journal of Physiotherapy 2017,* 63:175-181. PMID: 28652080

9. NHS Greater Glasgow and Clyde. MRC Grade. *NHSGGC 2018.* http://www.nhsggc.org.uk/about-us/professional-support-sites/cdm-local-enhanced-services/copd/symptoms/mrc-grade/

10. National COPD Audit Programme. Pulmonary rehabilitation: Beyond breathing better. *National COPD Audit Programme 2017,* 4-16.

11. Williams N. The MRC breathlessness scale. *Occupational Medicine 2017,* 67:496-497. https://doi.org/10.1093/occmed/kqx086

12. Liu Y, Dickerson T, Early F, Fuld J, Clarkson PJ. Understanding influences on the uptake of pulmonary rehabilitation in the East of England: An inclusive design/mixed methods study protocol. *BMJ Open 2018,* 8:e020750. doi:10.1136/ bmjopen-2017-020750

13. Keating A, Lee A, Holland AE. What prevents people with chronic obstructive pulmonary disease from attending pulmonary rehabilitation? A systematic review. *Chron Resp Dis 2011,* 8:89-99. PMID: 21596892

14. Cox NS, Oliveira CC, Lahham A, Holland AE. Pulmonary rehabilitation referral and participation are commonly influenced by environment, knowledge, and beliefs about consequences: A systematic review using the Theoretical Domains Framework. *Journal of Physiotherapy 2017,* 63:84-93. PMID: 28433238

15. Foster F, Piggott R, Riley L, Beech L. Working with primary care clinicians and patients to introduce strategies for increasing referrals for pulmonary rehabilitation. *Primary Health Care Respiratory Development 2016,* 17(3):226-237. PMID: 26072909

16. Johnston KN, Young M, Grimmer KA, Antic R, Frith PA. Barriers to, and facilitators for, referral to pulmonary rehabilitation in COPD patients from the perspective of Australian general practitioners: A qualitative study. *Primary Care Respiratory Journal 2013,* 22(3):319-324. PMID: 23797679

17. Melo G, Kleiner AFR, Lopes J, Zen GZD, Marson N, Santos T, Dumont A, Galli M, Oliveira C. Effects of virtual reality training on mobility in individuals with Parkinson's disease. *Gait & Posture 2018,* 42(4):473-480. https://doi.org/10.1016/j.gaitpost.2018.06.071

18. Yang WC, Wang HK, Wu RM, Lo CS, Lin KH. Home-based virtual reality balance training and conventional balance training in Parkinson's disease: A randomized controlled trial. *Journal of the Formosan Medical Association 2016,* 115:734-743. PMID: 26279172

19. Warland A, Paraskevopoulos I, Tsekleves E, Ryan J, Nowicky A, Griscti J, Levings H, Kilbride C. The feasibility, acceptability and preliminary efficacy of a low-cost, virtual-reality based, upper-limb stroke rehabilitation device: A mixed methods study. *Disability and Rehabilitation 2018. https://doi-org.ezproxy.mmu.ac.uk/10.1080/09638288.2018.1459881*

20. Shin JH, Park SB, Jang SH. Effects of game-based virtual reality on health-related quality of life in chronic stroke patients: A randomized, controlled study. *Computers in Biology and Medicine 2015,* 63:92-98. PMID: 26046499

21. Howard MC. A meta-analysis and systematic literature review of virtual reality rehabilitation programs. *Computers in Human Behaviour 2017.* 70:317-327.

22. Yamato TP, Pompeu JE, Pompeu SMAA, & Hassett L. Virtual reality for stroke rehabilitation. *Physical Therapy 2016,* 96(1):1508-1513. PMID: 27081204

23. Levack WMM, Watson J, Hay-Smith EJC, Davies C, Ingham T, Jones B, Cargo M, Houghton C, McCarthy B. Factors influencing referral to and uptake and attendance of pulmonary rehabilitation for chronic obstructive pulmonary disease: A qualitative evidence synthesis of the experiences of service users, their families, and healthcare providers (Protocol). *Cochrane Library,* 11.

24. May SM, Li JTC. Burden of chronic obstructive pulmonary disease: Healthcare costs and beyond. *Allergy and Asthma Proceedings 2015,* 36(1):4-10. PMID: 25562549

25. Llorens R, Noe E, Colomer C, Alcaniz M. Effectiveness, usability, and cost-benefit of a virtual reality-based telerehabilitation program for balance recovery after stroke: A randomized controlled trial. *Archives of Physical Medicine and Rehabilitation 2015,* 96:418-425. PMID: 25448245

26. Pauwels RA, Buist AS, Ma P, Jenkins CR, Hurd SS. Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease: National Heart, Lung, and Blood Institute and World Health Organisation Global Initiative for Chronic Obstructive Lung Disease (GOLD): Executive Summary, *Respiratory Care 2001* 46:798-825.

27. Rutton-van Molken MP, Oostenbrink JB, Tashkin DP, Burkhart D, Monz BU. Does quality of life of COPD patients as measured by the generic EuroQol five-dimension questionnaire differentiate between COPD severity stages? *Chest 2006,* 130:1117-1128. PMID: 17035446

28. Williams V, Bruton A, Ellis-Hill C, McPherson K. The importance of movement for people living with chronic obstructive pulmonary disease. *Qualitative Health Research 2011,* 21(9):1239-1248. PMID: 21511979

29. Casey M, Mulkerns A, O'Donnell C, McDonnell T. Pulmonary rehabilitation in COPD: Current practice and future directions. *COPD – An Update in Pathogenesis and Clinical Management:*

Chapter 6, InTech Open, 103-129. http://dx.doi.org/10.5772/intechopen.71218

30. Connolly MJ, Yohannes AM. The impact of depression in older patients with chronic obstructive pulmonary disease and asthma. *Maturitas 2016,* 92:9-14. PMID: 27621232

31. Hill K, Gesit R, Goldstein RS, Lacasse Y. Anxiety and depression in end-stage COPD. *European Respiratory Journal 2008,* 31:667-677. PMID: 18310400

32. Di Marco F, Verga M, Reggente M, Maria Casanova F, Santus P, Blasi F, Allegra L, Centanni S. Anxiety and depression in COPD patients: The roles of gender and disease severity. *Respiratory Medicine 2006,* 100:1767-1774. PMID: 16531031

33. Kuehl K, Schurmann W, Rief W. Mental disorders and quality of life in COPD patients and their spouses. *International Journal of Chronic Obstructive Pulmonary Disease 2008,* 3:727-736. PMID: 19281087

34. Katon W, Lin EH, Kroenke K. The association of depression and anxiety with medical symptom burden in patients with chronic medical illness. *General Hospital Psychiatry 2007,* 29:147-155. PMID: 17336664

35. Yohannes AM, Baldwin RC, Connolly MJ. Depression and anxiety in elderly outpatients with chronic obstructive pulmonary disease: prevalence, and validation of the BASDEC screening questionnaire. *International Journal of Geriatric Psychiatry 2000,* 15:1090-1096. PMID: 11180464

36. Agle DO, Baum, GL. Psychological aspects of chronic obstructive pulmonary disease. *Medical Clinical of North America,* 1977, 61, 749-758. DOI: 10.1016/S0025-7125(16)31294-9

37. Mikkelsen RL, Middelboe T, Pisinger C, Stage KB. Anxiety and depression in patients with chronic obstructive pulmonary disease (COPD). A review. *Nord J Psychiatry 2004.* 58(1): 65-70. PMID: 14985157

38. Paine NJ, Bacon SL, Bourbeau J, Tan WC, Lavoie KL. Psychological distress is related to poor health behaviours in COPD and non-COPD patients: Evidence from the CanCOLD study. *Respiratory Medicine 2019,* 146:1-9.

39. Robinson H, Williams V, Curtis F, Bridle C, Jones AW. Facilitators and barriers to physical activity following pulmonary rehabilitation in COPD: A systematic review of qualitative studies. *Primary Care Respiratory Medicine 2018,* 28(1):19.

40. Wedzicha JA, Bestall JC, Garrod R, Garnham R, Paul EA, Jones PW. Randomized controlled trial of pulmonary rehabilitation in severe chronic obstructive pulmonary disease patients, stratified with the MRC dyspnoea scale. *European Respiratory Journal 1998,* 12:363-369. PMID: 9727786

41. Dinesen B, Nonnecke B, Lindeman D, Toft E, Kidholm K, Jethwani K, Young HM, Spindler H, Oestergaard CU, Southard JA, Gutierrez M, Anderson N, Albert NM, Han JJ, Nesbitt T. Personalised telehealth in the future: A global research agenda. *J Med Internet Res 2016,* 18(3):e53. PMID: 26932229

42. Laver KE, Schoene D, Crotty M, George S, Lannin NA, Sherrington C. Telerehabilitation services for stroke. *Cochrane 2013.*

43. Peretti A, Amenta F, Tayebati SK, Nittari G, Mahdi SS. Telerehabilitation: Review of the state-of-the-art and areas of application. *JMIR Rehabilitation and Assistive Technologies 2017,* 4(2):1-9. PMID: 28733271

44. Tsai LLY, McNamara RJ, Moddel C, Alison JA, McKenzie DK, McKeough ZJ. Home-based

telerehabilitation via real-time videoconferencing improves endurance exercises capacity in patients with COPD: The randomised controlled TeleR study. *Respirology 2016,* 22:699-707. PMID: 27992099

45. Marquis E, Jung B, Schormans AF, Lukmanji S, Wilton R, Baptiste S. Developing inclusive educators: Enhancing the accessibility of teaching and learning in higher education. *International Journal for Academic Development 2016,* 21(4):337-349. https://doi.org/10.1080/1360144X.2016.1181071

46. Hou J, Yang R, Yang Y, Tang Y, Deng H, Chen Z, Wu Y, Shen H. The effectiveness and safety of utilising mobile phone-based programs for rehabilitation after lumbar spinal surgery: Multicenter, prospective randomized controlled trial. *JMIR 2019,* 7(2): e10201.

47. Chaplin, E., Hewitt, S., Apps, L., Bankart, J., Pulikottil-Jacob, R., Boyce, S., Morgan, M., Williams J, Singh S. Interactive web-based pulmonary rehabilitation programme: A randomised controlled feasibility trial. *BMJ Open Access 2017.* http://dx.doi.org/10.1136/bmjopen-2016-013682

48. Tabak M, Vollenbroek-Hutten MM, van der Valk PD, van der Palen J, Hermens HJ. A telerehabilitation intervention for patients with chronic obstructive pulmonary disease: A randomised controlled pilot trial. *Clinical Rehabilitation 2014,* 28:582-591. PMID: 24293120

49. Dinesen B, Huniche L, Toft E. Attitudes of COPD patients towards telerehabilitation: A cross-sector case study. *International Journal of Environmental Research and Public Health 2013,* 10:6184-6198. PMID: 24247995

50. Broadbent E, Garrett J, Jepsen N, Ogilvie VL, Ahn HS, Robinson H, Peri K, Kerse N, Rouse P, Pillai A, MacDonald B. Using robots at home to support patients with chronic obstructive pulmonary disease: Pilot randomized controlled trial. *JMIR 2018,* 20(2):e45.

51. Kairy D, Lehoux P, Vincent C, Visintin MA. A systematic review of clinical outcomes, clinical process, healthcare utilisation and costs associated with telerehabilitation. *Disability and Rehabilitation 2009,* 31:427-447. PMID: 18720118

52. Cimperman M, Makovec M, Trkman P, Stanonik M. Older adults' perceptions of home telehealth services. *Telemedicine Journal and e-Health 2013,* 19:786-790. PMID: 23931702

53. Crotty M, Killington M, van den Berg M, Morris C, Taylor A, Carati C. Telerehabilitation for older people using off-the-shelf applications: Acceptability and feasibility. *Journal of Telemedicine and Telecare 2014,* 20(7):370-376. PMID: 25399997

54. Shulver W, Killington M, Morris C, Crotty M. "Well, if the kids can do it, I can do it": The older rehabilitation patients' experiences of telerehabilitation. *Health Expectations 2016,* 20:120-129. PMID: 26890025

55. Tyagi S, Lim DS, Ho WH, Koh YQ, Cai V, Koh GC, Legido-Quigley H. Acceptance of tele-rehabilitation by stroke patients: Perceived barriers and facilitators. *Archives of Physical Medicine & Rehabilitation 2018.* PMID: 29902469

56. World Health Organisation. Chronic Obstructive Pulmonary Disease. *WHO 2017.* https://www.who.int/news-room/fact-sheets/detail/chronic-obstructive-pulmonary-disease-(copd)

57. Lozano R, Naghavi M, Foreman K, Lim S, Shibuya K, Aboyans V, Abraham J, Adair T, Aggarwal R, Ahn SY. Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: A systematic analysis for the global burden of disease study 2010. *The Lancet 2012,* 380(9859):2095-2128. PMID: 23245604

58. Salvi S. The silent epidemic of COPD in Africa. *The Lancet Global Health 2015,* 3(1):PE6-E7. https://doi.org/10.1016/S2214-109X(14)70359-6

59. Lomborg B. Global problems, local solutions: Costs and benefits. *Cambridge University Press 2013,* 143.

60. Harris D, Hayter M, Allender S. Improving the uptake of pulmonary rehabilitation in patients with COPD: Qualitative study of experiences and attitudes. *British Journal of General Practice 2008,* 58(555):703-710. PMID: 18826782

61. Jolly K, Majothi S, Sitch AJ, Heneghan NR, Moore DJ, Bates EJ, Turner AM, Bayliss SE, Price MJ, Singh SJ, Adab P, Fitzmaurice DA, Jordan RE. Self-management of health care behaviours for COPD: A systematic review and meta-analysis. *International Journal of COPD 2016,* 11:305-326.

62. Zwerink M, Brusse-Keizer M, van der Valk PDLPM, Zielhuis GA, Monninkohf EM, van der Palen J, Frith PA, Effing T. Self-management for patients with chronic obstructive pulmonary disease. *Cochrane Database of Systematic Reviews 2014,* 3. PMID: 24665053

63. Trappenburg, J., Jonkman N, Jaarsma T, van Os-Medendorp H, Kort H, de Wit N, Hoes A, Schuurmans M. Self-management: One size does not fit all. *Patient Education and Counselling 2013,* 92(1): 134-137. PMID: 23499381

64. Bryanton C, Bosse K, Brien M, McLean J, McCormick A, Sviestrip H. Feasibility, motivation, and selective motor control: Virtual reality compared to conventional home exercise in children with cerebral palsy. *Cyberpsychology & Behaviour 2006,* 9(2):123-128. PMID: 16640463

65. Brütsch K, Koenig A, Zimmerli L, Mérillat-Koeneke S, Riener R, Jäncke L, van Hedel JJ, Meyer-Heim A. Virtual reality for enhancement of robot-assisted gait training in children with neurological gait disorders. *Journal of Rehabilitation Medicine 2011,* 43(6):493-399. PMID: 21491072

66. Brütsch K, Schuler T, Koenig A, Zimmerli L, Mérillat S, Lünenburger L, Riener R, Jäncke L, Meyer-Heim A. Research influence of virtual reality soccer game on walking performance in robotic assisted gait training for children. *Journal of Neuroengineering and Rehabilitation 2010,* 15(7):1-9. PMID: 20412572

67. Camporesi C, Kallman M, Han JJ. VR solutions for improving physical therapy. In *Proceedings of IEEE Virtual Reality, Orlando, Florida 2013.*

68. Keller MS, Hannah J Park, Maria Elena Cunningham, Joshua Eleazar Fouladian, Michelle Chen & Brennan Mason Ross Spiegel. Public Perceptions Regarding Use of Virtual Reality in Health Care: A Social Media Content Analysis Using Facebook. *JMIR 2017,* 19(12):e419. PMID: 29258975

69. Cho KH, Lee KJ, Song CH. Virtual-reality balance training with a video-game system improves dynamic balance in chronic stroke patients. *The Tohoku Journal of Experimental Medicine 2012,* 228:69-74. PMID: 22976384

70. Rahman SARA. Efficacy of virtual reality-based therapy on balance in children with Down Syndrome. *World Applied Sciences Journal 2010,* 10(3):254-261.

71. Rostami HR, Arastoo AA, Nejad SJ, Mahany MK, Malamiri RA, Goharpy S. Effects of modified constraint-induced movement therapy in virtual environment on upper-limb function children with spastic hemiparetic cerebral palsy: A randomised controlled trial. *Neurorehabilitation 2011,* 31(4):357-365. PMID: 23232158

72. Mosadeghi S, Mark William Reid, Bibiana Martinez, Bradley Todd Rosen, Brennan Mason Ross

Spiegel. Feasibility of an Immersive Virtual Reality Intervention for Hospitalized Patients: An Observational Cohort Study. *JMIR Mental Health 2016*, 3(2):e28. PMID: 27349654

73. Chen CL, Hong WH, Cheng HY, Liaw MY, Chung CY, Chen CY. Muscle strength enhancement following home-based virtual cycling training in ambulatory children with cerebral palsy. *Research in Developmental Disabilities 2012*, 33:1087-1094. PMID: 22502833

74. Ma HI, Hwang WJ, Fang JJ, Kuo JK, Wang CY, Leong IF, Wang TY. Effects of virtual reality training on functional reaching movements in people with Parkinson's disease: A randomized controlled pilot trial. *Clinical Rehabilitation 2011*, 25(10):892-902. PMID: 21632652

75. Corbetta D, Imeri F, Gatti R. Rehabilitation that incorporates virtual reality is more effective than standard rehabilitation for improving walking speed, balance and mobility after stroke: A systematic review. *Journal of Physiotherapy 2015*, 61, 117-124. PMID: 26093805

76. Palma Lopes PJB, de Almeida Carvalho Duarte N, Lazzari RD, Oliveira CS. Virtual reality in the rehabilitation process for individuals with cerebral palsy and down syndrome: A systematic review. *Journal of Bodywork & Movement Therapies 2018*. https://doi.org/10.1016/j.jbmt.2018.06.006

77. Laver KE, George S, Thomas S, Deutsch JE, Crotty M. Virtual reality for stroke rehabilitation (Review). *The Cochrane Collaboration 2015*, 2. DOI: 10.1002/14651858.CD008349.pub3

78. Broeren J, Rydmark M, Sunnerhagen KS. Virtual reality and haptics as a training device for movement rehabilitation after stroke: A single-case study. *Arch Phys Med Rehabil 2004*, 85: 1247-1250. PMID: 15295748

79. Lewis GN, Rosie JA. Virtual reality games for movement rehabilitation in neurological conditions: How do the needs and expectations of the users? *Disability and Rehabilitation 2012*, 34:1880-1886. PMID: 22480353

80. Burridge JJ, Hughes AM. Potential for new technologies in clinical practice. *Current Opinion in Neurology 2010*, 23:671-677. PMID: 20962639

81. Bohil CJ, Alicea B, Biocca FA. Virtual reality in neuroscience research and therapy. *Nature Reviews Neuroscience 2011*, 12:752-762. PMID: 22048061

82. Threapleton K, Drummond A, Standen P. Virtual rehabilitation: What are the practical barriers for home-based research? *Digital Health 2016*, 2:1-11.

83. Braun V, Clarke, V. What can "thematic analysis" offer health and wellbeing researchers? *International Journal of Qualitative Studies in Health and Well-being 2014*, 9. http://dx.doi.org/10.3402/qhw.v9.26152

84. Braun V, Clarke V. Using thematic analysis in psychology. *Research in Psychology 2006*, 3(2):77-101.

85. Gill IJ, Wall G, Simpson J. Clients' perspectives of rehabilitation in one acquired brain injury residential rehabilitation unit: A thematic analysis. *Brian Injury 2012*, 26(7-8):909-920. PMID: 22571407

86. Holliday RC, Ballinger DC. Goal setting in neurological rehabilitation: Patients' perspectives. *Disability and Rehabilitation 2007*, 29(5):389-394. PMID: 17364791

87. Saunders JC, Byrne MM. A thematic analysis of families living with schizophrenia. *Archives of Psychiatric Nursing 2002*, 16(5):217-223. PMID: 12434327

88. Zoeckler N, Kenn K, Kuehl K, Stenzel N. Illness perceptions predict exercise capacity and psychological well-being after pulmonary rehabilitation in COPD patients. *Journal of*

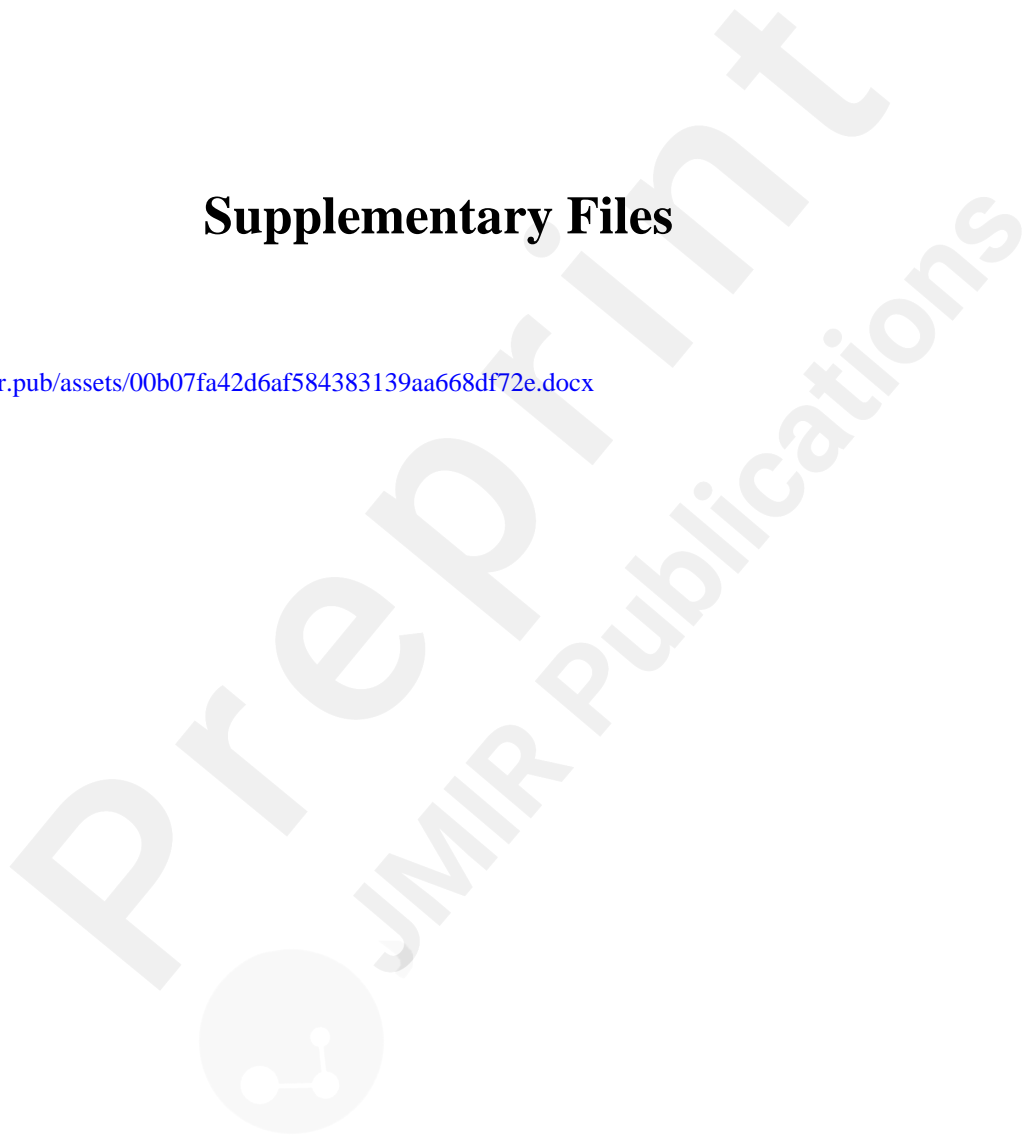*Psychosomatic Research 2014,* 76:146-151. PMID: 24439691

89. Didehbani N, Allen T, Kandalaft M, Krawczyk D. Virtual reality social cognition training for children with high functioning autism. *Computers in Human Behaviour 2016,* 62:703-711. https://doi.org/10.1016/j.chb.2016.04.033

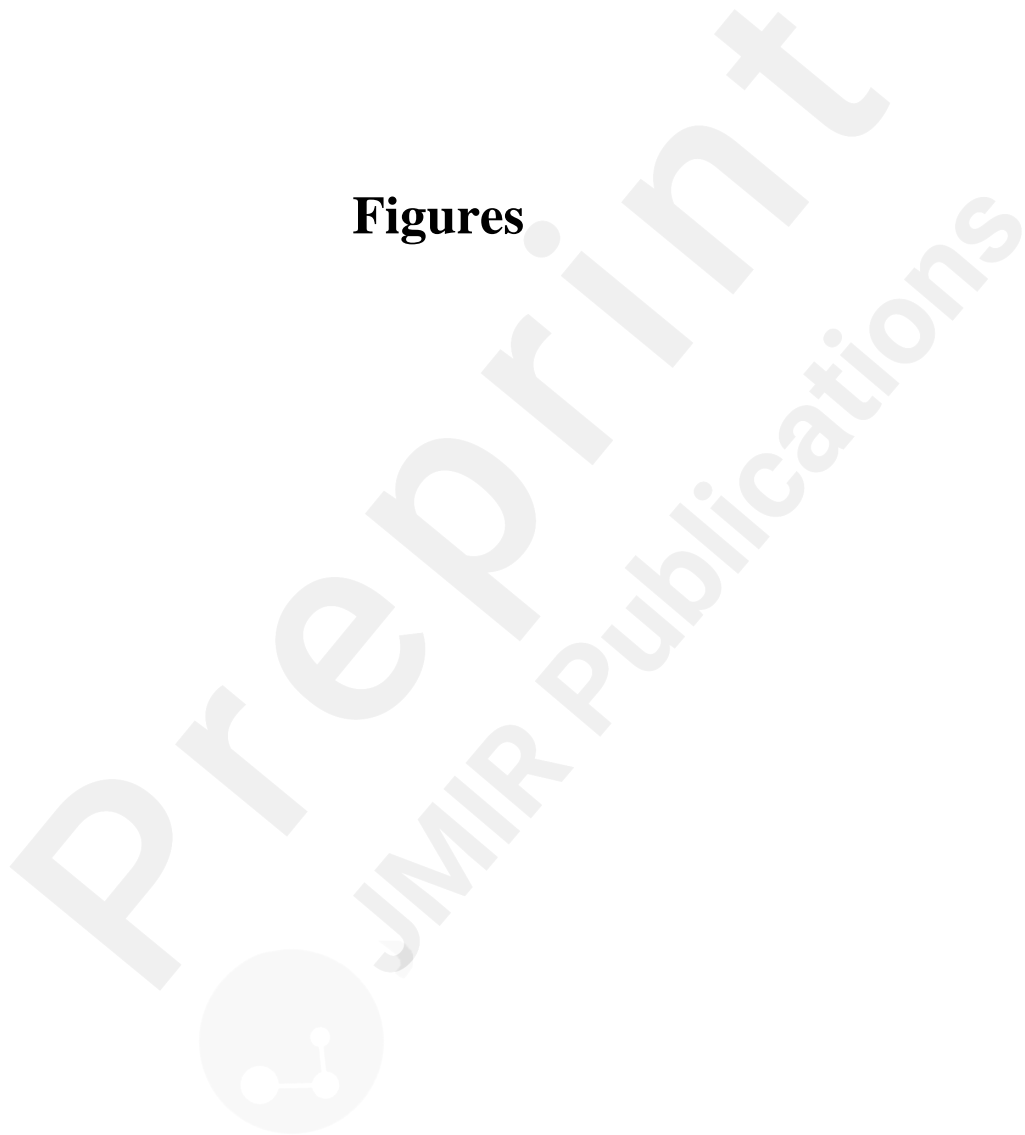90. British Lung Foundation. Chronic obstructive pulmonary disease (COPD) statistics. *British Lung Foundation 2018,* https://statistics.blf.org.uk/copd

Supplementary Files

Untitled.

URL: https://asset.jmir.pub/assets/00b07fa42d6af584383139aa668df72e.docx

Figures

Themes and description of each theme.

Themes	Description
Increased compliance	Significant increase in patients' compliance with pulmonary rehabilitation (i.e. conducting their exercises).
Increased engagement	Increased engagement in pulmonary rehabilitation when using VR due to enjoyment.
Physical improvements	Significant patients' physical improvements (i.e. strength, mobility, and flexibility).
Improved psychological well-being	Patients' psychological well-being has significantly improved.
Improved Health-related Quality of Life (HRQoL)	Patients feel healthier and fitter (i.e. they can confidently leave the house and socialise more than before).
Increased confidence	Significant improvements in confidence in terms of patients managing their condition, conducting daily activities, and physical exercises.
Patient satisfaction	Patients are satisfied with completing the PR in VR programme and achieving their short-term and long-term goals.
Increased feeling of security	Patients feel more secure, reassured, and confident to exercise knowing their physiological data is being remotely supervised.
Effective immersive learning	Effectiveness of immersive learning for COPD patients was demonstrated.
Personalised programmes	A recommendation is to provide programmes tailored to suit various levels of COPD.
Needs of technological improvements	Need for technological improvements of both the device (e.g. a more lightweight headset) and content of the application (e.g. additional functions to control the pace and standing up exercises) to improve patients experience.