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*Published in:*
2021 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)

*DOI (link to publication from Publisher):*
10.1109/VRW52623.2021.00052

*Publication date:*
2021

*Document Version*
Accepted author manuscript, peer reviewed version

*Citation for published version (APA):*
Høeg, E. R., Bruun-Pedersen, J. R., & Serafin, S. (2021). Virtual Reality-Based High-Intensity Interval Training For Pulmonary Rehabilitation: A Feasibility and Acceptability Study. In *2021 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)* (pp. 242-249). Article 9419097 IEEE. https://doi.org/10.1109/VRW52623.2021.00052

# Virtual Reality-Based High-Intensity Interval Training For Pulmonary Rehabilitation: A Feasibility and Acceptability Study

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## ABSTRACT

Chronic obstructive pulmonary disease (COPD) is an irreversible lung disease affecting over 174 million worldwide. Pulmonary rehabilitation (PR), including cardiovascular exercise such as high-intensity interval training (HIIT), can reduce frequency and severity of symptoms. However, oftentimes exercise regimens suffer from low motivation and poor adherence. This has previously been addressed by augmenting exercises with digital gaming experiences. However, to our knowledge no studies have yet investigated the feasibility of using immersive virtual reality (IVR) equipment on COPD-patients in HIIT. Through a longitudinal observational study, we investigated the feasibility and acceptability of using VR-headsets in a HIIT-based exercise program. Three older adults (age between 68-86) consented to participate. Heart rate, cadence, perceived exertion, nausea and motivation was measured both during VR-usage and standard training. Though the sample size implies low statistical power, which constitutes a serious limitation to external validity, motivation was retained during the study, and the use of VR did not lead to higher dyspnea, cardiovascular demands, nor serious adverse effects such as provoking exacerbation or instilling cybersickness. The results are encouraging and calls for further studies on how VR can be applied to HIIT exercise programs seeking to increase adherence. Future studies should investigate new ways of retaining motivation through higher interactivity or social collaborative experiences.

**Index Terms:** Human-centered computing—Human computer interaction (HCI)—Virtual reality;

## 1 INTRODUCTION

The world population is expected to reach 9.7 billion in 2050, which is nearly a 26% increase from today's levels which is assessed at 7.7 billion [57]; furthermore, the people over 65 will account for 1.7 billion (approximately 20%) of the world's population by then. Consequently, the growing elderly population will lead to an increase in chronic diseases, which challenges operating costs in healthcare systems around the world [66]. One of those chronic diseases is Chronic Obstructive Pulmonary Disease (COPD), an irreversible lung disease, which affects approximately 174.5 million people globally, and have over 3 million annual deaths [52].

Current treatments include exercising to improve fitness, health and pulmonary function [14]. However, exercising programs often suffer from low motivation, which affects both adherence and compliance [6, 7, 54]. Therefore, the need to create engaging new ways of facilitating exercise programs is highly relevant. Previous reviews describe overall good results with game-based interventions, including the use of virtual reality (VR) technology, for exercising within various fields such as stroke rehabilitation [42], dementia [60], Parkinson's disease [20] and balance training [3, 10].

Despite more than two decades of research applying VR to augment standard treatments in physical therapy and rehabilitation, the use of VR has largely eluded the field of COPD-rehabilitation [10, 22, 64]. Therefore, given the advent of affordable consumer-grade VR-equipment, investigating COPD-patients acceptability of VR is highly relevant. In this paper we present a longitudinal study, on three participants, to investigates the feasibility, acceptability and safety of using VR in COPD-rehabilitation for high-intensity interval training (HIIT).

## 2 BACKGROUND AND RELATED WORK

COPD is an umbrella term enclosing progressive lung diseases such as emphysema, chronic bronchitis as well as refractory asthma [15]. Most notably, symptoms include dyspnea (i.e., the uncomfortable experience of an abnormal shortness of breath), coughing, chest tightness and a general lack of energy (fatigue) [13, 40]. Patients with COPD suffer from an irreversible lung damage and functional decline which thus far remains incurable. However, treatments can relieve symptoms, delimit comorbidities (i.e., the co-occurrence of physical or mental health problems), reduce mortality risks, and improve the health-related quality of life (HRQoL) of those inflicted [13, 15].

### 2.1 Pulmonary Rehabilitation

Current treatment guidelines recommend Pulmonary Rehabilitation (PR) [14, 40, 43], which is a multidisciplinary treatment strategy involving physical activity, smoking cessation as well as teaching inhalation techniques and nutrition [15]. PR is an evidence-based treatment strategy which helps improve the wellbeing of COPD-patients. Furthermore, it reduces hospital admissions, decrease mortality rates in patients with recent exacerbations (i.e. an acute increase in the severity of the disease) [56]. Moreover, individuals with COPD belong to a group of patients who benefits significantly from physical activity including, but not limited to: strength, endurance, and high-intensity interval training (HIIT) [34] e.g., cardiovascular exercises such as running, swimming and biking [15].

Not all individuals affected by COPD are able to perform prolonged high-intensity training. As an alternative, interval training is frequently offered, which has proved similar benefits [4]. Interval training combines short periods of high-intensity intervals that are interspersed with lower training at a lower intensity [27]. Interval training using e.g. exercise bikes has the capacity to improve exercise flow by delimiting the need for resting periods [27].

### 2.2 Motivation and exercise adherence

Even though regular exercising is beneficial, training regimens oftentimes suffer from poor adherence from patients [6,47,54]. According to Bourbeau and Bartlett [6], higher patient self-efficacy is an underlying predictor of adherence to training programs, however, studies tend to evaluate only short term benefits [11]. The adherence to PR training regimens tends to regress over time, suggesting a general challenge with the retention of motivation [6]. Furthermore,

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Bourbeau and Bartlett note that older adults are more inclined towards lower adherence e.g. due to a greater amount of comorbidities and cognitive deficits [6]. Conversely, patients with higher motivation are more likely to perceive the regimens as being an important means to achieve recovery or optimal HRQoL, and thus are more likely to actively engage in rehabilitation programs [30].

### 2.3 Motivation through exergaming

Active video games (AVG), also sometimes known as exercise games or exertion games (both frequently abbreviated as exergames) have proven to help with motivation to exercise. However, exergames, as a term, has oftentimes been ambiguously used [35]. For this paper we define it, similar to Mueller et al. [36], as a digital gaming experience, where outcomes are achieved through physical exertion, and technology that tracks body movement to function as a form of physical activity. Exergaming has been applied in many rehabilitation contexts due to its ability to combine physical activities with game-inspired design mechanics [42]. According to several articles and systematic reviews, exergaming has previously been utilized to improve patient motivation and adherence [20, 24, 42]. Specifically, it has been applied to motivate exercise adherence in nursing home residents [8]; improving the quality of life of elderly people living with dementia [60], but it has also been used to demonstrate improvement in balance performance [3]; increase muscle strength [24] and functional mobility as well as motivation [51].

### 2.4 Defining Virtual Reality

Likewise the term ’virtual reality’ has previously been ambiguously used to describe human-computer interfaces of various kinds in many fields, rehabilitation science included [23, 44]. In a recent narrative review, Tieri and colleagues points out a pervasive problem with the inconsistent use of VR-terminology within the field of cognitive and motor rehabilitation [55]. They note that VR is oftentimes used to describe computer-based systems that utilize a 2D display (either monitor or projected), to deliver visual stimuli [55]. Thus, we deem it necessary to briefly outline an interpretation. For this article we define VR in terms of its immersive capabilities i.e., how faithfully the technology is able to reproduce and mediate multisensory integration and sensorimotor contingencies [50]. In a recent review Nilsson et al, classify this understanding of VR under the umbrella term: system immersion [37]. Furthermore, immersive VR (IVR) systems, usually delivered with stereoscopic head-mounted displays (HMD) or Cave automatic virtual environment (CAVE) systems [23, 50, 55], affords the perception of being physically present in a non-physical virtual environment (VE) [50]. While Tieri et al argues that only systems that fulfill the aforementioned criteria should be defined as VR [55], other authors Lange et al., [23] and Rizzo et al. [44], classify such systems (e.g. desktop displays or projected surfaces) as non-immersive VR (NVR).

### 2.5 Virtual reality in PR regimina

Most previous work introducing exergaming in the exercise regimen for rehabilitation has utilized readily available non-immersive commercial products such as Nintendo Wii, Wii Fit or Xbox Kinect$^{TM}$ [49]. Related to COPD, a recent scoping review by Colombo et al. investigated the technological aspects of VR for PR, and found similar tendencies. Most of the 21 interventions utilized commercially available systems, and only 3 out of the 21 included studies utilized IVR [11].

Studies using NVR include light intensity training for lung cancer treatment [18]; increasing exercise tolerance for COPD patients [31]; improving dyspnea and exercise adherence [62]. Other recent studies have included the use of NVR screen-based AVG for high-intensity training in PR [38, 45], as well as using Nintendo Wii Fit for home-based exercise training [1, 28] and supervised PR program [32], and for functional assessment Liu et al included the application of a treadmill to simulate a six-minute walk test (6MWT) [29]. Specifically for bike-based interventions, Colombo et al. conducted a study to investigate usability and acceptability of a NVR-application for personalized endurance training [12].

We only found two studies describing the use of IVR for PR [19, 33], presumably on the same participants, as the reported demographics are identical. The studies investigated IVR with 10 elderly COPD patients with very severe symptoms, between the age of 62-76 (n=10) for home-based training [19, 33]. Their main findings indicate that VR can increase confidence and help motivate a higher adherence to self-managing exercise regimens, with no reported adverse events.

### 2.6 Known adverse effects of VR

Cybersickness is a well-known adverse effect of exposure to VEs with symptoms occurring during, or after, exposure [41]. While symptoms are diverse, they frequently include headache, eye strain, disorientation, nausea or in rare cases vomiting [25, 41]. The most acknowledged theory on the cause of cybersickness, is the sensory conflict theory (SCT) which posits that the reason for discomfort stems from the brains attempt to integrate conflicting sensory stimuli from the vestibular system and the visual system [25]. That is, the visual system senses optical flow which is not perceived as either linear or angular acceleration by the vestibular system. However, cybersickness and motion sickness are not similar in all regards. Thus, the assumption of correlation when it comes to age may prove to be incorrect. In a study from 2005, Arns and Cerney found that adults over 50 reported more cybersickness-related symptoms than younger participants (n=387) when exposed to a CAVE-based VE [2]. Therefore the question of cybersickness is relevant to measure for this paper, as well as for future studies. NVR does not bring about the same challenges as IVR for the COPD patient population. Namely because immersion, as a product of the system, is positively correlated with self-reported levels of presence, which has been shown to be inversely related to cybersickness [63]. In this study, we introduce a bike-based VE, and the forward movement will induce optic flow which will cause the user to experience the illusion of self-motion (also known as vection). The more frequent exposure to changes in velocity, is arguably a greater cause of discomfort, and given the nature of the HIIT program, the virtual experience is more likely to lead to sensory mismatch and thus a higher risk of cybersickness [25].

Previous research has determined that IVR can cause genuine physiological responses to visual stimuli [48]. We therefore anticipate that exposure to a VE might lead to a higher level of physical performance. However, for the COPD patient population, overexertion can provoke adverse symptoms such as dyspnea [9], but mostly it is the fear of harm from overexertion that makes COPD-patients hesitant about pressuring themselves into higher intensity levels during training [9]. Therefore the addition of IVR might as well hamper performance, if participants becomes more anxious. Therefore, it is relevant to investigate whether or not the use of VR-headsets will cause discomfort or evoke undesired symptoms for participants. Hence, the purpose of this study can be summarized with the following research questions:

**Research question 1:** Does a VR bike-based exergame improve exercise-related motivation for patients with COPD?

**Research question 1.a:** if yes, can it be maintained for the duration of a 7-week program (retention of motivation).

**Research question 2:** Does the use of VR-equipment induce or hamper physical performance?

**Research question 3:** Will COPD-patients experience increasing dyspnea levels while wearing a VR-headset?

**Research question 4:** Will COPD-patients experience cybersickness?

Figure 1: Participant during a VR-session, currently biking with low intensity.

## 3 STUDY DESIGN AND METHODS

To our knowledge, this is the first study to investigate the use of HMD-based VR for the use in a HIIT regimens for COPD-patients. To investigate the feasibility and acceptibility of using VR within PR regimens, more specifically HIIT exercises, we conducted a longitudinal observational study measuring patient motivation, physical performance, exertion levels and cybersickness. The study was conducted over 8 weeks in an outpatient health center in the Danish municipality of Frederiksberg. After the final session, a semi-structured group interview was held with all participants. In accordance with the Helsinki Declaration the project protocol was submitted for consideration by the regional Research Ethics Committee, who concluded that the project did not require ethical approval. The Data Protection office at Aalborg University approved that the project (2019-899/10-0272) complied with General Data Protection Regulations (GDPR).

### 3.1 Participants

Three community-dwelling (i.e. older adults still living in a community and neither institutionalized nor living in nursing homes or sheltered housing) older males were recruited for the study. Participant A (86 years) had had COPD for approximately 20 years, participant B (77 years) had also had COPD for approximately 20 years, while participant C (68 years) attended the rehabilitation programme due to high risk of cardiovascular disease (CVD) and was not diagnosed with COPD. Enrolled participants were recruited from a newly started COPD-exercise group from a voluntary offer, running for eight consecutive weeks (two times a week). The group members were informed about the study's purpose, procedure and potential risk of adverse events. The volunteers were asked to sign an informed consent form in order to participate. As well as consent to the collection and publication of data and photos.

### 3.2 Materials and apparatus

The VE was created using Unity3D version 2018.2.21f1 and the Gaia terrain and scene generation system from Procedural Worlds that can quickly create large nature environments terrains, texturise them and procedurally add 3D models such as trees, rocks and villages [59]. Furthermore, we used the EasyRoads3D asset to create a road system [58]. With this tool the unity terrain's heightmap, created by Gaia, is conformed according to the road; thus making reiterations very malleable to adaptive changes. The VR-equipment used included two pairs of Oculus Rift Consumer Version 1 (CV1) headsets, connected to two high-end gaming computers with GTX1080 graphic cards. The exercise bikes used in the study were several *motion cycle 200 med* from Emotion Fitness GmbH & Co.

#### 3.2.1 Bike sensor

The participant's pedalling rate was detected with a custom-build wireless tracker attached to the pedal arm, measuring its angular velocity. The sensor was connected to the computer via wifi, and was connected to a Adafruit Feather HUZZAH microcontroller with an ESP8266 WiFi chip, and an ITG-3200 gyroscope, all powered by a 3.7V, 1200mA LiPo battery [17]. The participant's pedalling thus generated forward momentum through the VE following the curvatures of the road.

#### 3.2.2 Motivation

Motivation was measured using the post-experimental intrinsic motivation inventory (IMI) containing 18 items within the subscales of interest/enjoyment, perceived competence, pressure/tension, effort/importance and value/usefulness [46]. The statements were randomly ordered, and for each of them the participants indicated agreement on a 7-point likert scale ranging between *"not at all true"* (1) , *"partially true"* (4) and *"very true"* (7) . The interest/enjoyment subscale is the only subscale measuring intrinsic motivation directly, while the subscale pressure/tension is considered a negative predictor [46].

#### 3.2.3 Heart rate

To measure physical performance we utilized heart rate (HR). It was measured using several Polar FT7 sports watches connected to Polar H1 WearLink heart rate sensor transmitters worn under the shirt around the chest of the participants. To assure good conductivity the Wearlink pads had to be moistened with water, which was done before each session. The Polar FT7 records and diagnose several training effects by estimate (such as watt, fat burn etc.). However, we only needed the direct physiological measurements of mean pulse (calculated from the onset to the offset of the training session) as well as the peak pulse i.e., the maximal achieved pulse during the session, measured in beats per minute (BMP).

#### 3.2.4 Rating of perceived exertion

The rating of perceived exertion (RPE), also referred to as *The Borg-scale*, is a validated self-reporting measure of a subject's individual assessment of their experienced exercise intensity and dyspnea [5, 65]. The original scale ranges from 6-20. However, a modified version, the modified Borg category ratio scale (CR-10) ranging from 0 to 10, and is frequently used to assess patients level of dyspnea [15, 21, 29, 39, 49]. In this study patients were asked to rate their level of exertion using a verbal descriptor associated with a number on the scale at the end of each session. from *"nothing at all"* (0) to "very, very severe" (10).

#### 3.2.5 Measuring cybersickness

Due to time constraints in the training program, questionnaires had to be kept at a minimum. Instead of the SSQ, or other more extensive tests, we utilized a single-question verbal rating scale (VRS) as an indicator for the sense of dizziness (*did you experience any dizziness during the session?*). The participant would respond either: *"none"* (1), *"low"* (2), *"moderate"* (3) , *"high"* (4), or *"severe"* (5).

| | **Warm-up** | **Set 1** | | **Set 2** | | **Set 3** | |
|---|---|---|---|---|---|---|---|
| | *Step 0* | *Step 1* | *Step 2* | *Step 3* | *Step 4* | *Step 6* | *Step 7* |
| DUR: | 5min | 45s | 30s | 30s | 30s | 25s | 30s |
| INT: | low | high | low | high | low | high | low |

Table 1: The HIIT program used in the study. Set 1-3 was repeated 3 times before moving on to the next set, for a total amount of 14.5 minutes of training.

### 3.3 Procedure

The study in morning training sessions at the outpatient health center. All sessions were conducted simultaneously, in the same room as the other non-participating members of the COPD-exercise group. Upon arrival to the health center, the principal investigator (PI) fitted the all participants with the HR sensor and assured signal connection. Once the participants were prepared, they were instructed to get up on the bike and await further instructions.

As only 2 setups were available, participants took turn between sessions. The ones using VR-equipment were assisted by the PI in putting on and adjusting the HMD the first couple of times (after a few sessions participants were able to do it themselves with very little help).

The training sessions were guided by 1 to 2 physiotherapists who kept track of the time using a stopwatch. Furthermore, the physiotherapist would shout instructions to the group when they had to increase or decrease intensity following a 5 minute warm-up period. Low intensity level required the participants to adjust the bike's resistance level to a subjectively comfortable baseline level, which allowed them to bike at a comfortable level for a longer period of time, with a cadence i.e. pedal revolutions per minute (RPM) of approximately 60. In the high intensity interval, participants were asked to increase resistance levels by two, and increase cadence maximal capacity (approximately 80-100 rpm) for the duration of the interval whereupon both resistance and cadence was decreased to baseline level. Sessions lasted approximately 14.5 minutes (see table 1). Immediately at the end of session, HMDs were removed by the PI or the participants, and the they were asked to verbally rate perceived exertion and dizziness. Subsequently they were handed the physically printed IMI post-experiment questionnaire, which they filled out while sitting down in an antecedent waiting room. Upon completion, the participants joined the rest of the group and continued the daily training program, which involved strength training, 6MWT, stair climbing and other cardiovascular exercises.

## 4 RESULTS

Program attendance among participants was generally high. All in all, 33 sessions were logged between participants. Participant A attended 11/12 sessions (92%), and missed one session due to illness. Participant B attended 10/11 sessions (83%), missing one session from mistaking the time of it, and one due to illness. Participant C had perfect attendance.

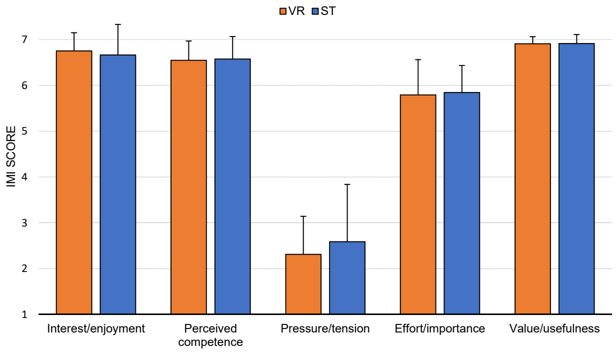

Figure 2: Bar graph presenting motivation scores for all IMI-subscales, aggregated for all participants and sessions, for both standard treatment (ST) and VR. The error bars represent standard deviations.

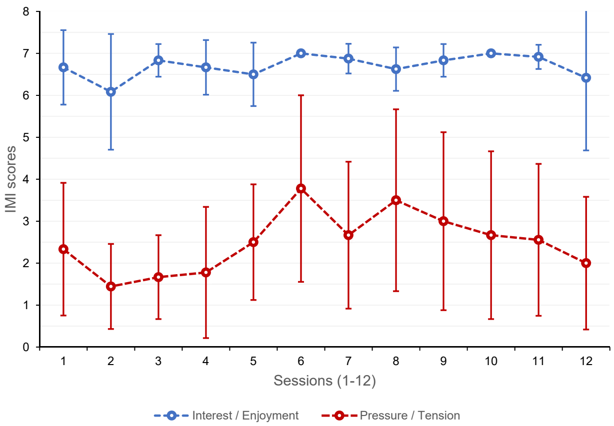

Figure 3: Line graph showing the mean motivation score for subscales *interest/enjoyment* and *pressure/tension* over the 12 sessions. The error bars represent standard deviations.

### 4.1 Motivation

The results of the IMI can be seen in fig. 2, for both standard treatment (ST) and VR, and showed an overall homogeneity among the participants' self-reported motivation. For *interest/enjoyment* participant A had a mean exercise motivation of 6.8±0.3, participant B rated it 6.9 ± 0.5, and participant C rated it 6.5±0.7. For *perceived competence* all participants had a mean rating of 6.7±0 (SD: A=0.3, B= 0.2, C=0.1). *Pressure/tension*, the negative measure of intrinsic motivation (meaning it is expected to be as low as possible, if participants are intrinsically motivated), had a higher dispersion between participants: A=2.9±1.3, B=2.2±1.1, and C=2.3±0.7. *Effort/importance* was lower than the other subscales but with higher variance. A = 6.8±0.6, B = 5.3±0.4 and C = 2.3±0.7 while for *value/usefulness*, A,C=7±0.1 and B=6.8±0.2. Due to large variance in the inter-item subscales, we performed a test for internal consistency using Cronbach's $\alpha$ (table 4.1).

For IMI measured both after VR- and ST usage, (fig. 2) there was a slight increase in the participants scoring of *interest/enjoyment* reported as mean and SD. For VR (6.8±0.4) and (6.6±0.7) for ST. For *Perceived competence* no noticeable difference was observed between VR (6.5±0.4) and ST (6.6±0.4), and neither did *value/usefulness* which was the same (7±0.2) for both. In *pressure/tension* there was a overall large difference in ratings between VR (2.3±0.8) and ST (3.7±1.3), however it is worth noticing that both had a very large dispersion. Similarly, *effort/importance* was rated slightly different between VR (5.8±0.8) and ST (6.9±0.3).

*Interest/enjoyment* remained high and consistent throughout the

| IMI Subscales | No. items (negative) | Subscales (M±SD) | C$\alpha$ | Mod. Subscales (M±SD) | Mod. C$\alpha$ |
|---|---|---|---|---|---|
| Int/Enj | 4 (2) | 6.7±.5 | .6 | 6.7±.5 | .7 |
| Per. comp. | 4 (1) | 6.6±.5 | .2 | 6.6±.4 | .8 |
| Pres/ten | 3 (2) | 2.5±1.1 | .3 | 3.5±1.4 | .4 |
| Eff/imp | 3 (1) | 5.8±.7 | .1 | 6.8±.3 | .1 |
| Val/use | 4 (0) | 6.9±.2 | .3 | 6.9±.2 | .4 |

Table 2: This table presents the Cronbach $\alpha$ (C$\alpha$) test used to measure scale reliability. The greatest source of variance was the 6 negative questions used in the IMI. The table also includes the modified subscales i.e., an increase in internal consistency after removing one negative item from each subscale. in the case of *perceived competence*, the internal consistency increase from .2 to .8 by removing one negative item.

study (session 1-12) but followed a slight increasing trend (see fig. 3, lines indicate motivation mean for all participants±SD). *pressure/tension* had more dispersion, but also followed a slight increasing trend over the first 6 sessions, and then decreased to baseline level.

### 4.2 Physical performance, exertion and cybersickness

Both participant A and B had approximately the same mean pulse throughout the study. The highest measured HR mean/HR peak for A (ST) was 117/231 bpm in session 6 (a very humid day), which was also the highest measured mean pulse (82bpm) for B, however B (while using VR) had the highest HR peak in session 1 (224bpm). C also had the highest measured mean/peak pulse in session 6 (120/144 bpm). On average, HR mean was approximately the same whether participants used VR-equipment (88.3±28) or exercised regularly (86.7±23.4). However, ST did yield a higher HR peak (121.3±45.4) than the intervention (114.2±45) (see table 3).

Perceived exertion (dyspnea) was identical for both ST and VR (see table 3). Participant A had the highest mean dyspnea level while exercising regularly 6.4 over 4.8 while using VR. The weather also had an effect on dyspnea levels for all participants (as well as motivation i.e. the highest reported sense of pressure/tension, at session 6, which was a humid day; Participant B reported the highest dyspnea level (7) which was also B's highest reported sense of dizziness in the cybersickess VRS ("high" (4)). Overall all participants reported CR-10 levels between 3-7. Participant A reported no sense of dizziness, and participant B reported no dizziness in 4 sessions and "low" in 2 sessions.

### 4.3 Post-study interview

In the post-study interview, all participants agreed that they did not experience a difference in motivation between using VR and ST. it was noted that there was a lack of synchronization between the slope of the hills in the VE and the intensity-level, and it was suggested that the intervals should match with the visuals (i.e. going up hill at high-intensity intervals and straight or downhill in low-intensity intervals). All of them agreed that it had been fun to try, but despite high IMI-ratings between all sessions the participants agreed that it became boring repeating the same path each time, and some variation in landscape was suggested. Furthermore, they agreed that it was "weird" hearing the other participants but not being able to see anyone within the VE. When pressed, one participant suggested that "it could be amusing" to see each other in the virtual space. When asked whether they would prefer more competitive element they all dismissed it without hesitation. They all agreed that it would be preferable to bike together than introducing competition into the VE.

It was further discussed whether or not the participants thought that VR made them dizzy, especially with reference to session 6. Participant C reasoned that it had more to do with the weather and the humidity that day than the VR-equipment. However, they all agreed that they got more susceptible to dizziness when they were at a higher level of exertion. Both participant B and C noted that they just looked down on the road if they experienced slight symptoms of dizziness, which helped obviate discomforts. When asked about whether they thought wearing the HMD was uncomfortable, or made it uncomfortable to breathe they replied no. When asked if they would try VR again, they all said yes without hesitating.

## 5 DISCUSSION

This study explored the feasibility and acceptibility of using VR in HIIT exercise programs for older adults. Based on existing findings on the use of VR for other patient populations, a larger difference in exercise-related motivation was anticipated. However, from the very beginning of the study, the level of motivation was already high, which can be attributed to the program being offered voluntarily, and thus participants are already present at their own volition. Presumably the participants belong to a group of COPD-patients who are already motivated to engage with physical exercise and challenge themselves, as opposed to the patients in Moorhouse et al's., study [33] who were highly vulnerable, and thus more likely to be at a lower level of motivation for physical activity. Moreover, it should not be neglected that the physiotherapists are already good at motivating exercise adherence, which affects the atmosphere and the mood of those present. Moreover, although there was a slight increasing trend in intrinsic motivation (based on interest/enjoyment) it's apparent that there's also an increasing trend in pressure/tension. That is a peculiar phenomenon, because according to Ryan and Deci, the subscale is a negative predictor for intrinsic motivation [46]. Therefore, we presumed a negative correlation between the two, which cannot be seen in the data. For RQ1, according to both IMI-scores and post-test interview the addition of VR did not increase participants motivation, and although motivation was retained for the duration of the study (RQ1.a), other reasons could easily be attributed.

Concerning the IMI-scale used in the study, the results suggests that reliability poses an immediate problem in terms of internal consistency. To avoid acquiescent - and extreme response bias, the scale suggests the use of several negative questions e.g. *"this activity did not catch my attention at all"* (interest/enjoyment) or *"This was an activity that I was not very good at"* (perceived competence). The 18-item questionnaire used in this study contained six reversed questions, and two of those were in the *Pressure/tension*-subscale, which was had the largest variance in responses. In an attempt to measure this inconsistency we utilized Cronbach's $\alpha$, and found only the interest/enjoyment subscale was at an acceptable level. Upon removing negative items with the highest variance, we managed to increase the alpha-value of all subscales, which suggests that negative questions are at least partially responsible for internal inconsistencies. We hypothesise that this is due to the participants misunderstanding the questions, or due to an increased cognitive demand, answers wrongful the opposite of what they intended. Therefore, we propose that other scales are used for future studies, or that negative questions are at least avoided. This is further substantiated by [61] who concludes that *reversed* questions do not effectively reduce response bias, but tend to lead to confusion instead. Furthermore, in a recent study by Goršič et al, the authors reached a similar conclusion, but for younger participants (aged 56.7 ± 14.7) [16]. Therefore these types of "reversed" questions are likely not suited for this population.

For RQ2 and RQ3, according to the rating of perceived exertion, interview and observations, the participants did not experience a higher degree of dyspnea when using the VR-equipment. Nor did they report any uncomfortable situations where the equipment restricted their breathing, performance or otherwise caused them physical or mental harm. Cybersickness (RQ4), based on the VRS (measuring dizziness), was generally low throughout the study. However, based on the post-study interview, there might be a tendency towards increase susceptibility to cybersickness as exertion gets higher. Future studies should consider this, and carefully monitor it, in order to establish whether COPD-patients are more likely to experience cybersickness when engages in high intensity training. Preferably using more comprehensive scales, such as the SSQ, measuring both baseline and post-test scores.

Another observation was made during a day of very high humidity (session 6). When the participants arrived they had more difficulty breathing than normally, and during sessions both dyspnea, heart rate and cybersickness were much higher than during other sessions. Future studies should consider that as a confounding variable and take initiatives to assure a more homogeneous atmosphere (e.g. through air conditioned training rooms), or at least be sure to register the daily humidity index as this may influence the patient

|  | A |  | B |  | C |  |
|---|---|---|---|---|---|---|
| **Outcomes** | **ST** | **VR** | **ST** | **VR** | **ST** | **VR** |
| HR mean (bmp) | 99±16.1 | 98.7±10.4 | 67±10.4 | 64.2±6.4 | 73 ± 27.7 | 115.8 ± 10.7 |
| HR peak (bmp) | 139±79.7 | 111±8.7 | 75.5±2.1 | 104.6±67 | 129.3 ± 11.5 | 139.2 ± 3.2 |
| Cadence mean±std (max) | - | 54±9 (76) | - | 54±12 (75) | - | 58±24 (91) |
| Borg (CR-10) | 6.4±0.9 | 4.8±1.7 | 4.5±1.3 | 5.3±1.3 | 4.8± 0.8 | 5.7± 0.8 |
| Dizziness |  | 1 ± 0 |  | 1.8 ± 1.3 |  | 1.3 ± 0.5 |

Table 3: This table presents the results from all recorded sessions (Mean±SD) from the physical performance (HR mean, HR peak), perceived exertion (Borg CR-10) and cybersickness (VRS), for participant A, B and C.

and cause exacerbation. The patients had no problems accepting the VR-equipment, nor had any hesitations towards continuing the use in VR. However, future applications need to consider ways to implement more interactive elements to keep patients in a state of flow. Furthermore, it was also noted by the participants, that the inconsistency between the virtual slope and the exerted effort they had to put into the training were at an odds with each other.

Based on the results, we did not find any indication that the COPD-patient population cannot use VR to engage in HIIT-based exercise programs. In terms of feasibility, VR can likely be applied to PR-interventions without any impact on exertion, cybersickness or comfort. However, several caveats which concern the validity of the study exists; the sample size of the study is too small to make any assumptions about external validity, the study participants likely cannot be considered highly vulnerable COPD-patients, as they were otherwise in good health, and only participant A and B were diagnosed with COPD. Moreover, there is another issue with representativeness. Women generally live longer than men, and are more likely to be diagnosed with COPD, and thus make up a higher proportion of those living with COPD. No women expressed interest in participating in the study during recruitment. Previous research report that women are more susceptible to experiencing cybersickness while using VR [53], therefore, adverse events related to the use of VR may not have been properly uncovered. Based on interview findings, we also saw how content- and interaction design for IVR rehabilitation applications likely have long-term impact on user experience and motivation. While positive aspects to the immersive experience may spark some initial motivation, they are not likely to neutralize repetitive parts to the experience design. Participants suggested *variation* - in this case e.g. to the landscape - but variation can be implemented in IVR rehabilitation by many standards. Besides visual diversity (of an explorative bike-based VE), this could also include more VE-based actions or events (e.g. non-playable virtual characters or environment features, behaving and interacting autonomously with each other and the user), or purposeful social facilitation and interaction within the VE itself. Participants described it as 'weird' to hear other participants, not visible within the VE. However, hearing *and* seeing the other person in the virtual space, perhaps even being able to cooperate or (perhaps even better) *collaborate* towards a shared goal, is likely to provide a tangible experience of variation to the rehabilitation exercise. Participants also mentioned that competition would likely not support the social experience, stating *"Perhaps young people want to compete. But not for us, not at our age. I don't want that. 'Cause then, if you ride, and you sprint on ahead 'cause you are in better shape than the others, you will be far ahead, and then it's the same as just riding alone. So that does not make a lot of sense"*. Participant responses also showed how the perceived ecology of the virtual space became noticeable to participants, for example through their constructed expectations to the pedal resistance of the exercise bike, while ascending the virtual hills. *"When you see this hill, you really think 'oooh, now it's gonna get tough', but then you don't feel that resistance and it becomes weird. So it would be great if you also had to put in the effort, and get that sensation (of the hill)"*. Considerations on multimodal IVR designs for virtual rehabilitation seems quite logical, as it could be an effective method to enhance users' connection to the simulated physicality of IVR-mediated exercises. Likely the immersive experience could be improved by adding interactivity and reward contingencies, generally extending the use of interaction design methodologies. Examples could include adding additional challenges, interactions or features to e.g. slope resistance, or perceptual feedback such as augmenting the force feedback through the pedals to simulate the virtual surfaces. In addition to this, the IVR HIIT biking application could be made even more focused on motivating the HIIT exercise tasks. One example could be to design tracks, so that each high-intensity segment of the exercise, would be represented in the virtual environment, for instance, as specifically placed small hills and slopes of very specific length and frequency. HIIT programs of different difficulty could be designed, based on therapist requirements, to suit individual strength or durability levels. Such implicit guidance inside the VE, of when and how long to place high-intensity output and when to relax, could make a HIIT oriented IVR application useful, even without a therapist present. Also it could even, theoretically, be eligible for testing as home-based therapy or telerehabilitation, to afford the social benefits of group exercising, while complying with necessary stay-at-home restrictions, or related challenges, due to the present COVID-19 pandemic (or future ones) [26].

We encourage further research of higher quality to investigate the use of VR-based HIIT in PR to increase motivation and retention. However, studies should be performed with healthcare professionals present in case of exacerbation. To our knowledge, this is the first study to describe the use of HMD-based immersive VR for the use in a HIIT regimen in pulmonary rehabilitation and potentially the first step towards adding VR to the rehabilitation-tools available to the physiotherapists in Frederiksberg municipality, with the purpose of increasing exercise adherence for citizens with pulmonary disabilities.

## 6 CONCLUSIONS

This study explored the feasibility and acceptability of applying VR to PR-programs. Motivation was retained throughout the exercise program, but this might be attributed to other factors as this was not a comparative study. The use of VR in PR, in this instance, did not lead to higher dyspnea, cardiovascular demands, tension or any serious adverse events such as provoking exacerbation or instilling severe cybersickness. The results are encouraging for further studies of how VR can be applied to HIIT exercise programs for COPD-patients to increase exercise adherence. But VR-based prototypes should afford higher variability, higher interactivity or social collaborative experiences.

## 6.1 Acknowledgements

The authors wish to thank Research and Development Therapist Nanna Aue Sobol for assisting with the methodology of the study, as well as feedback on early drafts. We also wish to thank to physiotherapists of Frederiksberg Health Center, most notably Susanne Frederiksen, whom without their support, this study would not have become a reality. Finally, thanks to Frederiksberg municipality for funding the research.

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