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Mixed-Methods Assessment of a Virtual Reality-Based System for Pulmonary Rehabilitation

Aileen S. GABRIEL[1], Te-Yi TSAI, Taulant XHAKLI and Joseph FINKELSTEIN
Department of Biomedical Informatics, University of Utah, Salt Lake City, UT, USA
ORCiD ID: Aileen S. Gabriel https://orcid.org/0000-0002-5872-9078

Abstract. Barriers to pulmonary rehabilitation (PR) (e.g., finances, mobility, and lack of awareness about the benefits of PR). Reducing these barriers by providing COPD patients with convenient access to PR educational and exercise training may help improve the adoption of PR. Virtual reality (VR) is an emerging technology that may provide an interactive and engaging method of supporting a home-based PR program. The goal of this study was to systematically evaluate the feasibility of a VR app for a home-based PR education and exercise program using a mixed-methods design. 18 COPD patients were asked to complete three brief tasks using a VR-based PR application. Afterward, patients completed a series of quantitative and qualitative assessments to evaluate the usability, acceptance, and overall perspectives and experience of using a VR system to engage with PR education and exercise training. The findings from this study demonstrate the high acceptability and usability of the VR system to promote participation in a PR program. Patients were able to successfully operate the VR system with minimal assistance. This study examines patient perspectives thoroughly while leveraging VR-based technology to facilitate access to PR. The future development and deployment of a patient-centered VR-based system in the future will consider patient insights and ideas to promote PR in COPD patients.

Keywords. Virtual reality, telerehabilitation, chronic obstructive pulmonary disease, qualitative analysis

1. Introduction

Pulmonary rehabilitation (PR) is an effective treatment for lowering dyspnea symptoms, increasing exercise tolerance, and improving the quality of life in patients diagnosed with Chronic obstructive pulmonary disease (COPD) [1-2]. Participation in traditional center-based PR is deterred by financial constraints, transportation issues, motivation, limited awareness, and a lack of perceived benefits [3]. Virtual reality (VR) has been identified as a potential alternative approach to facilitate exercise therapy for rehabilitation [4] Despite the potential benefits, the use of virtual reality to promote the participation of PR in COPD patients has yet to be explored. This study aimed to assess the usability of a potential VR application to support patient engagement in patients diagnosed with COPD.

[1] Corresponding Author: Aileen S. Gabriel, E-mail: aileen.gabriel@utah.edu

2. Methods

The study was approved by the Institutional Review Board at the Icahn School of Medicine at Mount Sinai. Patients with COPD and a recent history of acute exacerbation were recruited. Purposive sampling was used to recruit potential participants until information saturation was reached or no new or relevant information could be discovered from the collected data [3]. 18 participants consented and enrolled in the current study. During the data collection phase, a trained researcher demonstrated how to use the VR system, which comprised a headset and two controllers (Figure 1). The Virtual Reality app to facilitate PR education and exercise in COPD patients was developed in our lab for the Oculus Quest 2 system using the Unity Development Platform. We had two groups of participants; the first group reviewed the PR education component (*n = 9)*, and the second group reviewed the PR exercise component *(n = 9)*. The average age of patients in the PR education group was 74±7 years ranging between 61 and 84 years old. For the PR exercise group, the average age of the patients was 72±9 years ranging between 55 and 84 years old. The PR education component was based on the concepts of adult learning theories. This educational framework has previously been proven to be beneficial for interactive patient education [6]. Participants in both groups were instructed to use the VR headset and controllers to navigate the VR app. Once the VR headset was placed on the participant, the device was preset to access the VR education or exercise app to increase ease of navigation. The system interface was designed to be controlled by a single button represented by the trigger of the right or left controller. Participants completed a series of pre-task surveys that included a Socio-demographics questionnaire, a BRIEF Health Literacy Screening Tool [7], and a Pre-PR Education Questionnaire [8].

Participants in the PR education group were instructed to use the VR headset and controllers to complete 3 main tasks: 1. Navigate and open the VR education component; 2. Complete the education modules; and 3. Answer multiple-choice questions. The education content consisted of five modules: Introduction; Rehabilitation overview; Exercise overview; Rehabilitation benefits; Telerehabilitation overview. Each module included a brief 2–3-minute instructional video and four multiple-choice questions (Figure 2). All multiple-choice questions must be answered correctly to move on to the next module. The system allows the participant to self-correct any wrong answers until the correct answer is selected for each question.

Figure 1. Oculus Quest 2 Virtual Reality System.

Figure 2. Example multiple-choice question for PR education component

Participants in the PR exercise group were instructed to use the VR headset and controllers to complete 3 main tasks: 1. Navigate and open the VR exercise component;

2. Select an exercise and review the guided exercise instructions; 3. Perform an exercise using the guided exercise instructions (Figure 3-4).

Figure 3. PR exercise component - User login

Figure 4. PR exercise component – Start menu

Quantitative and qualitative data were collected from both participant groups including Post-Task questionnaires, an Attitudinal Survey [9], a Heuristic evaluation [10], and a System Usability Scale (SUS) [11]. A semi-structured qualitative interview which comprised open-ended questions about the participant's experience with the content, interface, and process of using a VR-based system to facilitate a PR education or PR exercise program was conducted. Thematic analysis was used to organize, analyze, and understand important patterns and themes in qualitative data [12-13].

3. Results

The mean post-task scores (scale of 1-5) for the VR education and exercise app were 4.74, 4.85, and 4.89 across the three tasks. The usability of the VR education and exercise app was rated highly on the heuristic evaluation with a mean score of 4.7 on a scale between 1 and 5 (Table 1). The overall average System Usability Score (SUS) was 95.8. With a maximum SUS score of 100, a score of 95.8 indicates a strong usability evaluation, which is typical of individuals who enjoy an app or website and will suggest it to their friends. The results of the thematic analysis of the semi-structured qualitative interviews revealed that participants highly accepted the VR system content, interface, and process. A concept map [14] was created based on the qualitative research results to depict facilitators and barriers across the three usability areas: app content, app interface, and app process (Table 2).

Table 1. Heuristic evaluation of a VR-based system to engage with pulmonary rehabilitation.

		N	Minimum	Median	Maximum	Mean
1	The system shows you what's going on and gives you feedback (visibility)	9	4	5	5	**4.89**
2	Language and words make sense (match between system and real world)	9	3	5	5	**4.78**
3	There are clearly marked 'exits', buttons to go back or move forward (control/freedom)	9	4	5	5	**4.89**
4	Words, situations, and actions mean the same thing as elsewhere (consistency)	9	3	5	5	**4.44**

5	There are very few errors, and minimal error-prone conditions (error prevention)	9	3	5	5	**4.78**
6	Instructions are obvious, no need to remember how things work (recognition, not recall)	9	3	5	5	**4.67**
7	The system works for both new and expert users (flexibility, efficiency of use)	9	4	5	5	**4.89**
8	Information is streamlined and relevant (aesthetic / minimalist design)	9	1	5	5	**4.44**
9	Error messages are clear and in plain language (recognize, recover from errors)	9	3	5	5	**4.67**
10	Help is available, searchable, and relevant (help and documentation)	9	4	5	5	**4.89**

Table 2. Concept map of the reported barriers and facilitators by usability area

Content		Interface		Process	
Facilitators	Barriers	Facilitators	Barriers	Facilitators	Barriers
Interactive and more visual way to exercise	No reported problems	The larger screen size of the VR app is easier to follow	Needed guidance on how to operate the controllers	Values the PR education material information that is not included in YouTube (e.g., research, benefits)	Does not think the program would impact their ability to participate
Increase in engagement	Difficulty hearing due to low volume	Similar to an in-person interaction in comparison to printed materials	Dislikes the length and the black screen while the VR app is loading	The convenience of using the VR exercise app at home is beneficial	No reported concerns or problems with the VR app
Simple and/or easy to understand		Did not need assistance using interface	Difficulty finding the VR app button for the first time	Feels more involved while using the VR app than other PR education programs	
Novel and exciting way to exercise		Easy to use	Thinks the headset is heavy	Time-saving	
Informative and relaxing			Cannot see the controller with the headset on		

4. Discussion

The current study aimed to investigate the feasibility of using a VR-based system to facilitate a home-based PR education and exercise program. In a convenience sample of VR-naïve COPD patients, we demonstrated high acceptance and usability of a VR format to deliver interactive PR education and exercise content. The preliminary data show that using VR in combination with fitness training and COPD education is feasible and well tolerated by COPD patients. Patients expressed appreciation for the immersive virtual environment and the absence of interruptions, and they felt at ease interacting with the VR exercise app on their own to acquire instructional and instructive information for completing the PR exercises. Our findings support prior research that shows that utilizing principles from adult learning theories in avatar-based or mobile interactive platforms might dramatically boost disease-specific knowledge in patients with low health literacy and limited computer abilities [15]. In this initial study, we acknowledge the absence of a comparable control group as a limitation. While the goal of this study was to assess the usability of a VR-based system to support engagement in PR, the ability to draw definitive conclusions about its impact is hindered without a control group. In future

studies, we intent to address this limitation by incorporating a well-matched control group to provide a more comprehensive assessment.

5. Conclusion

The findings from this study provide a mixed-methods evaluation of the feasibility of a VR-based system to support a home-based PR education and exercise program. COPD patients demonstrated high satisfaction and acceptance of using a VR system to engage in educational and instructional content about pulmonary rehabilitation. These findings will be considered in the future development and implementation of a patient-centered VR-based pulmonary rehabilitation program.

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