

Development of a Multivariable Predictive Model for Adherence to Remotely Monitored Home-Based Pulmonary Rehabilitation in Patients with Chronic Obstructive Pulmonary Disease

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Purpose: This study aimed to explore factors affecting adherence to remote home-based pulmonary rehabilitation (PR) in patients with stable chronic obstructive pulmonary disease (COPD) and to develop a predictive model.

Patients and Methods: This multicenter, cross-sectional survey study included 86 patients who underwent 12 weeks of health education-integrated, home-based PR with remote monitoring. Patients were stratified into high-completion (HC, $\geq 70\%$) and low-completion (LC, $< 70\%$) groups. Demographic data, clinical features, and psychological parameters were analyzed. Receiver operating characteristic curve and area under the curve (AUC) analyses evaluated the predictive performance of key indicators. Binary logistic regression identified four predictors: Pulmonary Rehabilitation Adapted Index of Self-Efficacy (PRAISE), Outcome Expectations for Exercise Scale (OEE), Montreal Cognitive Assessment (MoCA), and Visual Analog Scale (VAS). These components formed an optimized predictive model with corresponding formula and cutoff values.

Results: A cross-sectional survey of 71 patients, 44 in the HC group and 27 in the LC group, revealed significantly higher scores in the HC group in the following domains of the 36-Item Short Form Health Survey (SF-36), including physical functioning, role limitations due to physical health, role limitations due to emotional problems, energy/fatigue, mental health, and social functioning, as well as in the MoCA scores (all p -values < 0.05). Significant intergroup differences were also observed in PRAISE, OEE and VAS scores (all $p < 0.001$). PRAISE (AUC = 0.810), OEE (AUC = 0.784), MoCA (AUC = 0.719), and VAS (AUC = 0.801) demonstrated discriminatory power in assessing PR adherence. The combined predictive model achieved an AUC of 0.895 (95% confidence interval: 0.812–0.977, $p < 0.05$), with 77.8% sensitivity and 93.2% specificity.

Conclusion: Social cognitive theory (SCT) originated from social learning theory. It explains human behavior through a triadic, dynamic, and reciprocal model. This model posits continuous interaction among an individual's behavior, cognitive factors, and environmental context. The four-variable predictive model, based on SCT, effectively evaluates adherence to home-based PR under remote monitoring in patients with COPD. Among the indicators in the four-variable model, PRAISE shows potential as a target for intervention to enhance PR completion rates.

Keywords: pulmonary rehabilitation, remote monitoring, social cognitive theory, predictive model, chronic obstructive pulmonary disease, patient compliance

Introduction

Chronic obstructive pulmonary disease (COPD) is the third leading cause of death worldwide,¹ with an estimated global prevalence of approximately 10.3% and about 3 million deaths attributed to it annually.^{2,3} In China, the prevalence of COPD ranges from 8.4% to 11.8%.^{4,5} COPD impairs daily functioning and increases medical expenditures owing to acute exacerbations, imposing a significant disease burden on countries worldwide.^{6,7}

Pulmonary rehabilitation (PR) can alleviate symptoms of dyspnea in patients with COPD, enhance exercise capacity, and improve quality of life and emotional well-being.^{8,9} It has become one of the cost-effective strategies for comprehensive COPD management.¹⁰ However, the widespread application of traditional PR in China remains limited.¹¹ A major challenge is low compliance among patients undergoing long PR treatment cycles, which require at least 6–8 weeks to be effective,¹² particularly during the global COVID-19 pandemic. Factors contributing to low compliance include geographical location, cultural environment, economic status, transportation conditions, and symptom severity.^{8,13} The Global Initiative for Chronic Obstructive Lung Disease 2023 guidelines highlighted remotely monitored home-based PR as a strategy for comprehensive COPD management.¹⁴ A multicenter clinical study found that patients participating in remotely monitored PR demonstrated better adherence compared with those in conventional programs,¹⁵ suggesting that this approach may enhance patient compliance.

A previous study found that providing patients with COPD with health education on exercise methods, health regimens, and nutrition, along with PR-related knowledge before initiating PR treatment, significantly improved the completion rate of PR (58.7% vs 75%, $p < 0.001$).¹⁶ Although patients exhibit varying behavioral choices, no single factor fully explains the behavioral patterns they adopt.¹⁷

Social cognitive theory (SCT), proposed by psychologist Albert Bandura, emphasizes the dynamic interaction between individual behavior, cognition, and environment. By integrating cognitive driving factors such as self-efficacy and outcome expectations with environmental facilitating factors, SCT provides a solid theoretical framework for health promotion.^{18,19} Although previous studies have confirmed the sustainability and effectiveness of behavioral interventions based on SCT in improving physical activity levels among COPD patients,^{20,21} moreover, this approach provides a framework to explain behavior change and identify barriers and facilitators in home-based activity.²² However, the integration of this theory with PR programs remains insufficient.²³ This highlights a knowledge gap in the field. Specifically, the application of behavior change theory to analyze factors influencing remote home-based PR and to promote its completion rate has not been sufficiently explored.

This study aims to identify specific factors, based on SCT, that affect adherence to remotely monitored home-based PR and to construct a behavioral predictive model for evaluating PR adherence. Furthermore, it seeks to determine effective intervention strategies to improve the completion rate of remotely monitored home-based PR, thereby enhancing the effectiveness of PR treatment for patients with COPD.

Materials and Methods

Study Design and Participants

This cross-sectional survey study aimed to evaluate the correlation between adherence behavior and specific factors in patients with stable COPD eligible for a 12-week remotely monitored home-based PR program, based on SCT. Patients with moderate-to-severe COPD in the stable stage were recruited from May 2021 to November 2023 from the outpatient departments of Respiratory and Critical Care Medicine and Rehabilitation Medicine across three teaching hospitals in Nanjing: The First Affiliated Hospital of Nanjing Medical University, the Geriatric Hospital of Nanjing Medical University, and the Affiliated BenQ Hospital of Nanjing Medical University. Stable COPD is defined as COPD not in an active exacerbation.²⁴ A total of 83 patients met the inclusion and exclusion criteria.

Sample Size Calculation

Based on previous research and preliminary trial results,²⁵ a significance level of $\alpha = 0.05$ and a power of $1 - \beta = 0.2$ were chosen. We conducted a sample size calculation based on one ROC curve power calculation. Using the `power.roc.test` function from the `pROC` package in R, assuming an AUC of 0.80, a two-sided significance level of 0.05, and a power of 0.80, the required minimum sample size was estimated to be 26 participants.

Inclusion and Exclusion Criteria

Inclusion criteria: (1) Aged 40–75 years (male or female); (2) Diagnosed according to the Global Initiative for Chronic Obstructive Lung Disease 2021 criteria and in a clinically stable phase, with no respiratory tract infections or acute COPD exacerbations in the past four weeks;²⁶ (3) Be able to complete pulmonary function tests and classified as having moderate-to-severe COPD; (4) Be capable of conducting home-based PR training under remote supervision; (5) Be able to use a smartphone application; (6) Had not participated in other clinical trials in the past six months; (7) Did not engage in routine daily exercise, such as Baduanjin, Tai Chi, or other aerobic exercises; (8) Informed consent and voluntary participation.

Exclusion criteria: (1) Congestive heart failure with New York Heart Association class III or higher; resting heart rate > 100 beats/min; (2) Forced expiratory volume in one second (FEV_1) $> 80\%$ predicted or $< 25\%$ predicted; (3) Uncontrolled chronic diseases, such as hypertension (resting blood pressure $\geq 160/100$ mmHg) or diabetes (random blood glucose > 16.7 mmol/L or glycosylated hemoglobin $> 7.0\%$); (4) Advanced cancer or terminal illness; (5) Unstable ischemic heart disease, left heart failure, or myocardial infarction not stably controlled within six months prior to enrollment, as well as acute coronary syndrome or a history of percutaneous coronary intervention or coronary artery bypass grafting within the past three months; (6) Joint, peripheral vascular, or neurological disorders impairing basic motor ability; (7) Mental or cognitive impairments; (8) Females who were breastfeeding, pregnant, planning to become pregnant during the study period, or of childbearing potential without effective contraceptive methods; (9) Concurrent severe liver or kidney disease, with severe liver disease defined as cirrhosis, portal hypertension, and variceal bleeding, and severe kidney disease including dialysis and kidney transplantation.

Participants adhered to the interventions as depicted in [Figure 1](#).

Ethics

This study was registered with the Chinese Clinical Trial Registry (No. ChiCTR2100042700) at <http://www.chictr.org.cn/showproj.aspx?proj=120859>. It was approved by the Ethics Committee of the First Affiliated Hospital of Nanjing Medical University (No. 2021-SR-024), the Geriatric Hospital of Nanjing Medical University (No. 2021-010), and the Affiliated BenQ Hospital of Nanjing Medical University (No. 2021-KL011).

PR Intervention

All patients with COPD received remotely monitored home-based PR treatment combined with health education. Participants followed a Baduanjin exercise video on a smartphone equipped with the remote rehabilitation application (Sukang R+ Health App, v.5.1.40.0; Chengdu Shangyi Information Technology Co., Ltd., Chengdu, China) while wearing a heart rate monitor (RecoveryPlus H1; Chengdu Shangyi Information Technology Co., Ltd). The PR regimen required a minimum of one hour of cumulative exercise per day, three days per week, for a total of 12 weeks. After completing the treatment, patients were grouped based on their attendance rate. Those with a completion rate of less than 70% were classified into the low completion (LC) group, whereas those with a completion rate of 70% or higher were classified into the high completion (HC) group.²⁷

Outcome Measures

A cross-sectional survey was conducted using one-on-one questionnaires after the completion of the 12-week PR treatment program. Based on SCT, the survey aimed to assess the willingness of patients with COPD to undergo PR treatment. It included various variables, such as demographic characteristics, clinical features, and psychological

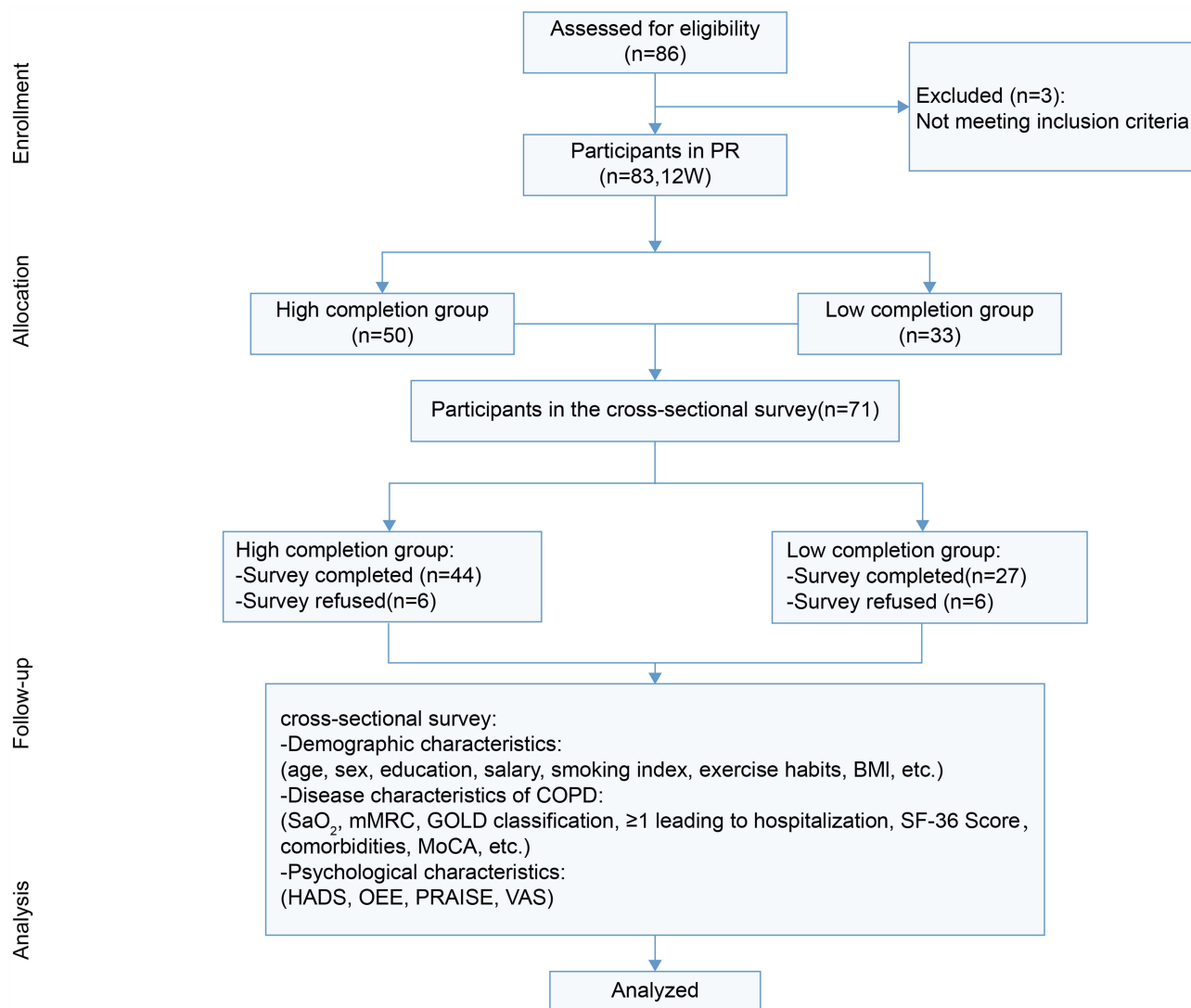


Figure 1 Research flow diagram.

attributes (Figure 2).¹⁸ The specific evaluation indicators were the Short Form Health Survey (SF-36), Hospital Anxiety and Depression Scale (HADS), Pulmonary Rehabilitation Adapted Index of Self-Efficacy (PRAISE), Outcome Expectations for Exercise Scale (OEE), Montreal Cognitive Assessment (MoCA), and Visual Analog Scale (VAS). The conceptual model diagram is presented in Figure 2.

SF-36

SF-36 is a concise, self-administered questionnaire that assesses eight dimensions of health: physical functioning (PF), role limitations due to physical health (RPH), role limitations due to emotional problems (REP), energy/fatigue (EF), mental health (MH), social functioning (SF), bodily pain, and general health. It also includes a single-item scale for health transition. Each domain is scored on a scale from 0 to 100, with higher scores indicating better health-related quality of life.²⁸

HADS

HADS is a widely used psychological tool designed to detect anxiety and depression in patients within medical settings. It consists of two seven-item subscales—one for anxiety and one for depression—totaling 14 items. Each subscale is scored from 0 to 21, with higher scores indicating more severe symptoms.²⁹

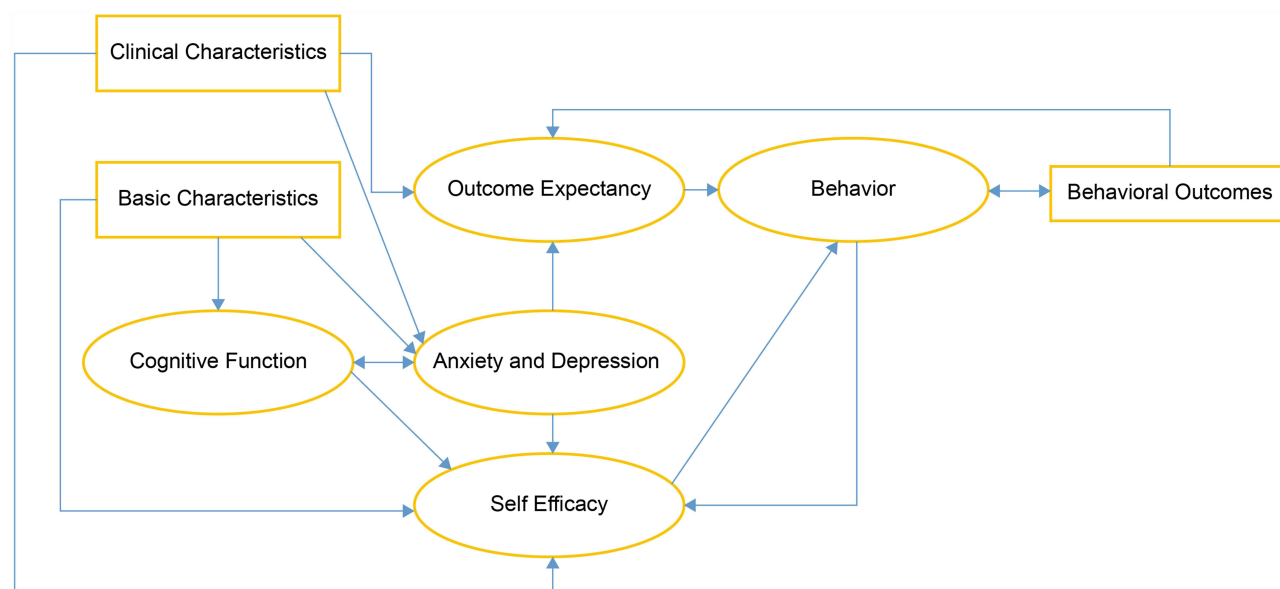


Figure 2 Model concept diagram.

PRAISE

PRAISE is a 15-item questionnaire that measures confidence in adapting to the challenges of PR. Scores range from 15 to 60, with higher scores indicating greater self-efficacy.³⁰

OEE

OEE is a psychological tool used to assess expectations about the outcomes of engaging in regular physical activity. The version used in this study includes 13 items, each scored on a Likert scale, with higher scores indicating stronger outcome expectations.³¹

MoCA

MoCA is a widely used screening tool for mild cognitive impairment. It assesses multiple cognitive domains, including visuospatial and executive functions, memory, language, visual construction skills, abstract thinking, calculation, and orientation. The total score is 30, with a score ≥ 26 considered normal. For individuals with 12 years of education or less, one additional point is added, with the maximum score remaining 30. Scores of 23–25 suggest possible mild cognitive impairment, whereas scores of 19–22 accompanied by difficulties in daily activities typically indicate progression from mild cognitive impairment to dementia. Scores ≤ 18 indicate dementia.³²

VAS

VAS is a psychological measurement tool commonly used to assess pain intensity. It is a simple, unidimensional instrument consisting of a horizontal line, typically 10 cm long, with verbal descriptions at both ends. In this study, it was used to measure willingness to participate in PR. The left end represents “no willingness”, whereas the right end signifies “strong willingness”. Patients mark the point on the line that best reflects their current level of willingness. The distance from the left end to the mark is measured and serves as a quantitative indicator of willingness.^{33,34}

Statistical Analysis

Statistical analysis was performed using SPSS 26.0 software (IBM Corp). All quantitative variables were tested for normality using the Shapiro–Wilk test. Data with a normal distribution are presented as mean \pm standard deviation and analyzed by t-test for intergroup comparisons, while non-normally distributed data are expressed as median (minimum–maximum) and analyzed using Mann–Whitney U-test. Qualitative and ordinal data were presented as

relative numbers and analyzed using the chi-square (χ^2) test. The receiver operating characteristic curve and area under the curve (AUC) were used to evaluate the discriminatory power of key indicators for the completion of remote PR treatment. An AUC closer to 1 indicated higher discriminatory performance. Specifically, an AUC > 0.85 signified excellent discrimination, an AUC between 0.70 and 0.85 indicated moderate discrimination, an AUC between 0.50 and 0.70 suggested low discrimination, an AUC of 0.50 implied no discriminative ability, and an AUC < 0.50 indicated indicates poor discrimination (worse than random chance). Indicators with moderate or higher discrimination were selected as candidate predictors. A binary logistic regression method was then used to construct a predictive model by combining candidate predictors, thereby establishing an optimal model. Mediation effect analysis was conducted to evaluate the relationship between variables. A p-value < 0.05 was considered statistically significant.

Results

A total of 83 patients were included in the trial. At 12 weeks, 12 patients declined to sign the survey consent forms and were excluded from the study. Ultimately, all 71 participants completed the survey by the end of the remote PR program, representing 86% of the original 83 patients enrolled in PR. Among them, 44 were in the HC group, and 27 were in the LC group. No significant differences in demographic characteristics were observed between the two groups (all $p > 0.05$). These characteristics included age, sex, education level, monthly income, smoking index, body mass index, exercise habits, and family history of COPD.

Disease and Psychological Characteristics of Patients

After treatment, no statistically significant differences were observed between the two groups in HADS and SF-36 scale scores for bodily pain, general health, and health transition (all $p > 0.05$). However, the HC group scored significantly higher than the LC group in PF, RPH, REP, EF, MH, SF, MoCA (all $p < 0.05$). Significant differences were also observed between the two groups in PRAISE, OEE, and VAS scores (all $p < 0.001$, [Table 1](#)).

Screening Key Indicators Between the Two Groups

Significant differences were observed between the two patient groups in the SF-36 scale scores for PF ($p = 0.034$), RPH ($p = 0.009$), REP ($p = 0.029$), EF ($p = 0.018$), MH ($p = 0.013$), and SF ($p = 0.013$). Furthermore, significant differences were found in the PRAISE ($p = 0.000$), OEE ($p = 0.000$), MoCA ($p = 0.002$), and VAS scores ($p = 0.000$, [Table 1](#) and [Figure 3](#)).

Selection of Candidate Indicators for Constructing a Predictive Model

Based on the 10 statistically significant key indicators, ROC curve analysis was conducted to calculate the discriminatory power of each indicator for PR completion. Moderate discrimination was observed for PRAISE (AUC = 0.810, 95% confidence interval [CI]: 0.689–0.931, $p < 0.05$), OEE (AUC = 0.784, 95% CI: 0.672–0.896, $p < 0.05$), MoCA (AUC = 0.719, 95% CI: 0.593–0.845, $p < 0.05$), and VAS (AUC = 0.801, 95% CI: 0.688–0.913, $p < 0.05$). Low discrimination was observed for PF (AUC = 0.649, 95% CI: 0.519–0.778, $p < 0.05$), RPH (AUC = 0.671, 95% CI: 0.537–0.805, $p < 0.05$), REP (AUC = 0.636, 95% CI: 0.500–0.772, $p < 0.05$), EF (AUC = 0.667, 95% CI: 0.535–0.799, $p < 0.05$), MH (AUC = 0.676, 95% CI: 0.542–0.811, $p < 0.05$), and SF (AUC = 0.660, 95% CI: 0.523–0.797, $p < 0.05$; [Table 2](#)).

Among the 10 key indicators, the PRAISE, OEE, MoCA, and VAS scores demonstrated discriminatory power for determining whether remote PR could be completed. Therefore, these four indicators were selected as candidate indicators for evaluating PR treatment adherence outcomes. Logistic regression analysis was conducted to construct a predictive model combining these indicators. The model showed an AUC of 0.895 (95% CI: 0.812–0.977, $p < 0.05$), with a sensitivity of 77.8% and a specificity of 93.2%, indicating good discrimination in assessing adherence to remote PR ([Figure 4](#)). Additionally, to evaluate the internal validity of the predictive model, we performed a leave-one-out cross-validation (LOOCV) analysis. The corresponding ROC curve demonstrated an AUC of 0.838 (95% CI: 0.732–0.943)

Table 1 Patient Characteristics

Variable	PR High Completion Group (n=44)	PR Low Completion Group (n=27)	Z/t/ χ^2 Value	p-value
Demographic characteristic data				
Age, years M (Min-Max)	69 (51–78)	70 (52–77)	−0.137	0.891
Male sex, No (%)	40 (90.9)	26 (96.3)	0.742	0.389
Education, years M (Min-Max)	12 (6–19)	12 (6–16)	−1.662	0.097
Monthly salary, yuan M (Min-Max)	6000 (100–18,000)	5000 (0–20,000)	−1.477	0.140
Smoking index, pack-year M (Min-Max)	28 (0–100)	30 (0–100)	−0.988	0.323
Exercise habits, No (%)			1.893	0.169
Yes	30 (68.2)	14 (51.9)		
Not	14 (31.8)	13 (48.1)		
Family history of COPD, No (%)			1.386	0.239
Yes	12 (27.3)	11 (40.7)		
Not	32 (72.7)	16 (59.3)		
Body mass index, kg/m ² (SD)	24±3.3	23±4.0	0.514	0.350
Disease characteristic data				
SaO ₂ (%) M (Min-Max)	97 (92–99)	96 (90–99)	−0.309	0.758
mMRC, No (%)			1.959	0.581
0	8 (18.2)	3 (11.1)		
1	18 (40.9)	12 (44.4)		
2	14 (31.8)	7 (25.9)		
3	4 (9.1)	5 (18.5)		
4	0 (0)	0 (0)		
GOLD, No (%)			1,693	0,193
1	0 (0)	0 (0)		
2	34 (77.3)	17 (63.0)		
3	10 (22.7)	10 (37.0)		
4	0 (0)	0 (0)		
≥1 leading to hospitalization, No(%)			0.878	0.349
Yes	6 (13.6)	6 (22.2)		
Not	38 (86.4)	21 (77.8)		
Comorbidities				
Hypertension, No (%)			0.151	0.697
Yes	20 (45.5)	11 (40.7)		
Not	24 (54.5)	16 (59.3)		
Diabetes, No (%)			0.001	0.974
Yes	5 (11.4)	3 (11.1)		
Not	39 (88.6)	24 (88.9)		
Ischaemic heart disease, No (%)			1.269	0.260
Yes	5 (11.4)	1 (3.7)		
Not	39 (88.6)	26 (96.3)		
Hyperlipidemia, No (%)			0.029	0.864
Yes	2 (4.5)	1 (3.7)		
Not	42 (95.5)	26 (96.3)		
Cerebral apoplexy, No (%)			1.922	0.166
Yes	3 (6.8)	0 (0)		
Not	41 (93.2)	27 (100)		
SF-36 Score				
Physical functioning M (Min-Max)	88 (45–100)	80 (0–100)	−2.116	0.034
Role limitations due to physical health	100 (0–100)	50 (0–100)	−2.626	0.009

(Continued)

Table 1 (Continued).

Variable	PR High Completion Group (n=44)	PR Low Completion Group (n=27)	Z/t/ χ^2 Value	p-value
M (Min-Max)				
Role limitations due to emotional problems M (Min-Max)	100 (0–100)	67 (0–100)	–2.187	0.029
Energy/fatigue M (Min-Max)	88 (30–100)	75 (30–100)	–2.368	0.018
Mental health M (Min-Max)	88 (48–100)	80 (40–100)	–2.494	0.013
Social functioning M (Min-Max)	100 (50–100)	88 (25–100)	–2.473	0.013
Pain M (Min-Max)	100 (45–100)	90 (52.5–100)	–1.956	0.051
General health (SD)	50±20.1	52±17.3	1.142	0.635
Health change M (Min-Max)	50 (0–75)	25 (0–75)	–0.978	0.328
Montreal Cognitive Assessment (MoCA) M (Min-Max)	25 (19–29)	21 (10–27)	–3.097	0.002
Psychological characteristic data				
HADS				
Anxiety, No (%)			5.105	0.078
Yes	0 (0)	3 (11.1)		
Not	44 (100)	24 (88.9)		
Depression, No (%)			1.265	0.531
Yes	3 (6.8)	4 (14.8)		
Not	41 (93.2)	23 (85.2)		
The Pulmonary Rehabilitation; Adapted Index of Self Efficacy (PRAISE) M (Min-Max)	48 (38–60)	40 (31–60)	–4.370	0.000
Expectation of Exercise Results Scale (OEE) (SD)	54±6.5	47±6.0	0.331	0.000
Visual Analog Scale (VAS score) M (Min-Max)	8 (0–10)	6 (0–10)	–4.233	0.000

based on DeLong’s method, indicating that the model retained good discriminative ability upon internal validation. The prediction formula is as follows:

$$\text{logit}(p) = 14.609 - 0.217(\text{MoCA}) - 0.102(\text{PRAISE}) - 0.049(\text{OEE}) - 0.451(\text{VAS}).$$

In clinical practice, when $\text{logit}(p) \geq -0.463$, that is, $0.217(\text{MoCA}) + 0.102(\text{PRAISE}) + 0.049(\text{OEE}) + 0.451(\text{VAS}) \leq 15.072$, we can assume that the patient will withdraw from the remote PR program.

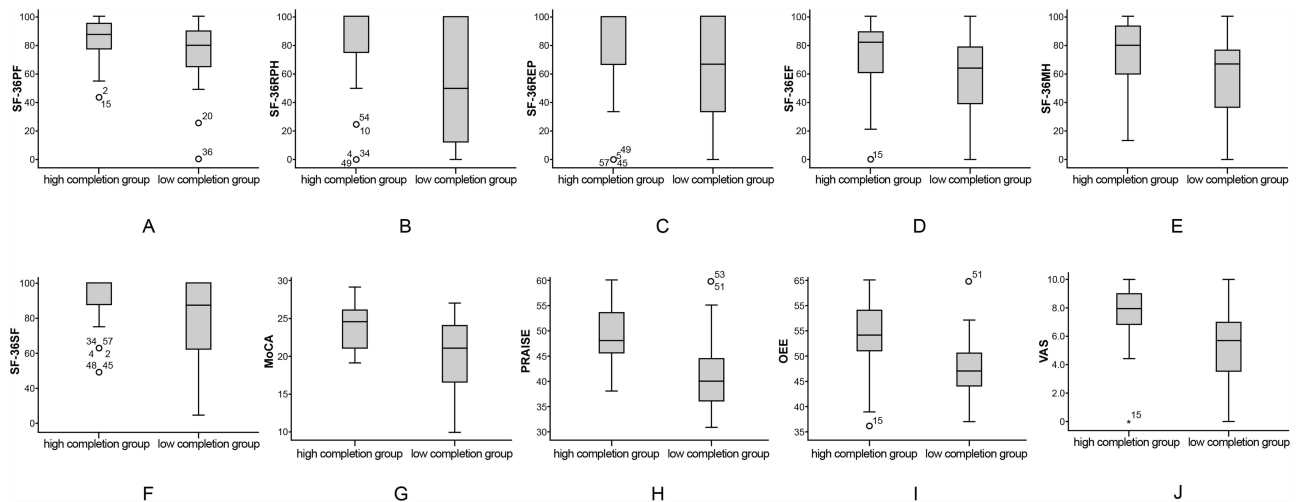


Figure 3 Analysis of differences in screening key indicators between high completion group and low completion group (A–J) Differences in the distribution of SF36PF, SF-36RPH, SF-36REP, SF-36EF, SF-36MH, SF-36SF, MoCA, PRAISE, OEE and VAS between high and low completion groups ($p < 0.05$).

Table 2 AUC, Sensitivity, and Specificity of Different Variables

Key Indicators	AUC	95% CI	Sensitivity (%)	Specificity (%)	Cut Off value
SF-36 (PF)	0.649	0.519–0.778	29.5	96.3	92.5
SF-36 (RPH)	0.671	0.537–0.805	81.8	51.9	62.5
SF-36 (REP)	0.636	0.500–0.772	70.5	55.6	83.4
SF-36 (EF)	0.667	0.535–0.799	65.9	66.7	82.5
SF-36 (MH)	0.676	0.542–0.811	65.9	74.1	86.0
SF-36 (SF)	0.660	0.523–0.797	81.8	48.1	81.3
MoCA	0.719	0.593–0.845	86.4	48.1	20.5
PRAISE	0.810	0.689–0.931	90.9	70.4	43.5
OEE	0.784	0.672–0.896	77.3	74.1	50.5
VAS	0.801	0.688–0.913	65.9	85.2	7.5

Abbreviations: SF-36, Short Form 36 Health Survey; PF, Physical functioning; RPH, Role limitations due to physical health; REP, Role limitations due to emotional problems; EF, Energy/fatigue; MH, mental health; SF, Social functioning; MoCA, Montreal Cognitive Assessment; PRAISE, the Pulmonary Rehabilitation Adapted Index of Self Efficacy; OEE, Expectation of Exercise Results Scale; VAS, Visual Analog Scale.

Analysis of the Mediating Effects of Indicators in the Model

Given that OEE influenced behavioral outcomes through PRAISE, mediation analysis revealed a statistically significant negative mediation effect size of -0.0843 (95% CI: -0.2206 to -0.0230 , $p < 0.05$). Moreover, after controlling for the

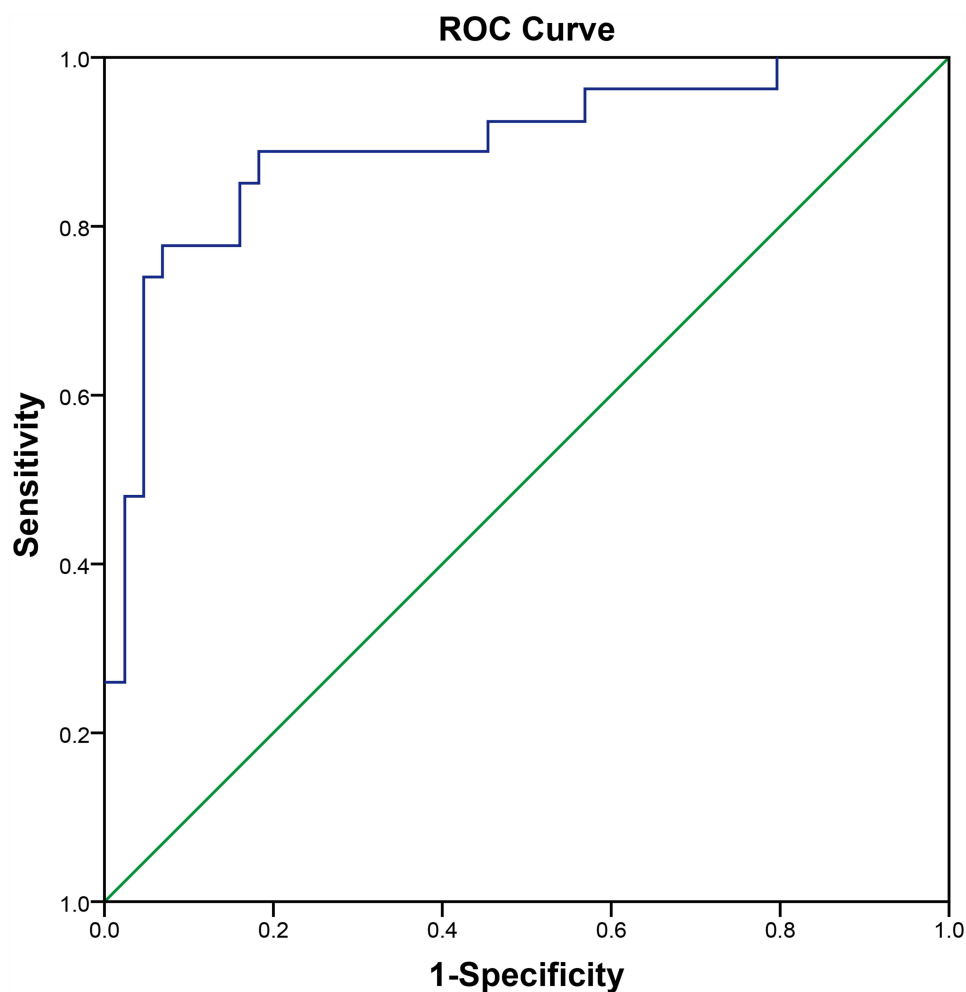


Figure 4 The subject work characteristic curve and area under the curve of the combined pulmonary rehabilitation adaptation self-efficacy (PRAISE), Outcome Expectations for Exercise Scale (OEE), Montreal cognitive assessment (MoCA), and patient willingness to receive pulmonary rehabilitation treatment (VAS score) model predicting the adherence of remotely monitored home-based pulmonary rehabilitation.

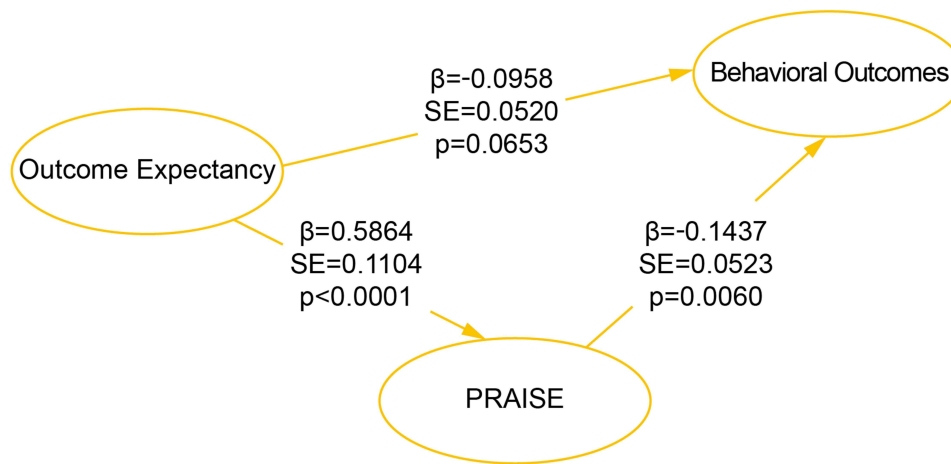


Figure 5 PRAISE plays a mediating role in the impact of OEE on behavioral outcomes.

Abbreviations: PRAISE, the Pulmonary Rehabilitation Adapted Index of Self Efficacy; OEE, Expectation of Exercise Results Scale.

mediator variable PRAISE, the influence of OEE on behavioral outcomes became statistically insignificant (regression coefficient: -0.0958 , 95% CI: -0.1977 to 0.0061 , $p > 0.05$). These findings indicate that PRAISE plays a mediating role in the relationship between OEE and behavioral outcomes and acts as the sole mediator, also known as a complete mediator (Figure 5). In Figure 5, $\beta = -0.0958$ corresponds to an odds ratio (OR) of 0.9086 (95% CI: 0.8206 – 1.0061 , $p > 0.05$), indicating no significant relationship between OEE and compliance. However, $\beta = 0.5864$ ($p < 0.0001$) demonstrates a significant positive association: each one-unit increase in OEE leads to an average increase of 0.5864 units in PRAISE. Additionally, $\beta = -0.1437$ (OR = 0.8661 , $p = 0.006$) suggests a significant link between higher PRAISE and improved compliance.

Mediation analysis indicated that when MoCA influenced behavioral outcomes through PRAISE, the mediation effect size was -0.1242 (95% CI: -0.2980 to -0.0361 , $p < 0.05$), indicating statistical significance. Furthermore, after controlling for the mediator variable PRAISE, the direct effect of MoCA on behavioral outcomes became statistically insignificant (regression coefficient: -0.1753 , 95% CI: -0.3585 to 0.0079 , $p > 0.05$). Therefore, PRAISE serves as a mediating factor in the relationship between MoCA and behavioral outcomes, functioning as the sole intermediary variable, also referred to as complete mediation (Figure 6).

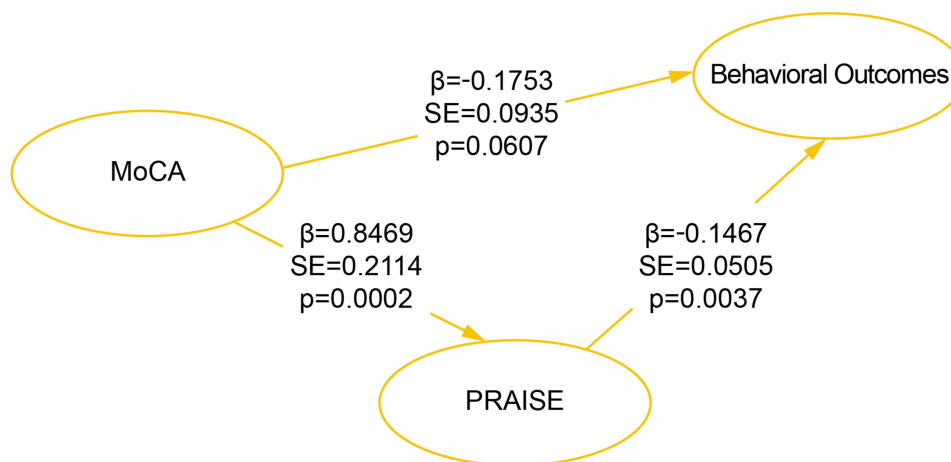


Figure 6 PRAISE plays a mediating role in the impact of cognition on behavioral outcomes. $\beta = -0.1753$ (OR = 0.8392 , $p = 0.0607$) suggests no significant association between MoCA and compliance. By contrast, $\beta = 0.8469$ ($p = 0.0002$) indicates that each one-unit increase in MoCA corresponds to an average increase of 0.8469 units in PRAISE, supporting a significant positive relationship. Additionally, $\beta = -0.1467$ (OR = 0.8636 , $p = 0.0037$) reveals a significant positive association between higher PRAISE and compliance.

Abbreviations: MoCA, Montreal Cognitive Assessment; PRAISE, the Pulmonary Rehabilitation Adapted Index of Self Efficacy.

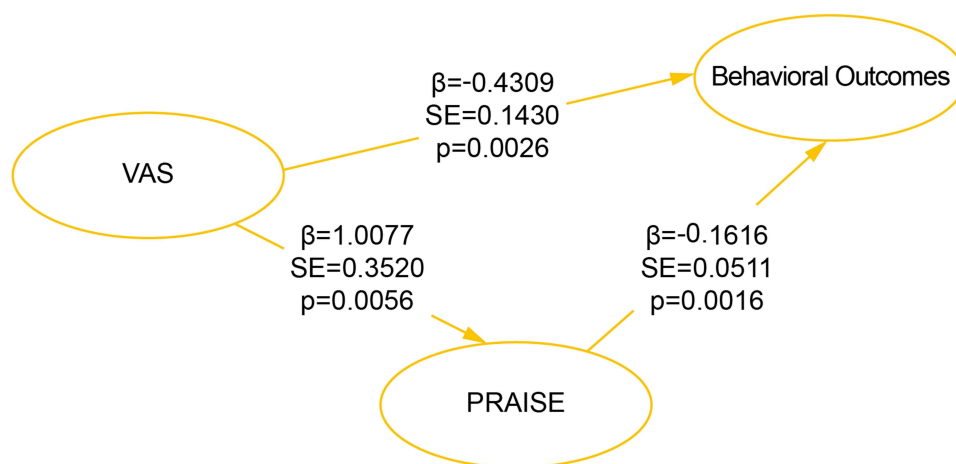


Figure 7 PRAISE partially mediates the effect of VAS on behavioral outcomes. A significant negative association was observed between high VAS and high compliance ($\beta = -0.4309$; OR = 0.6499, $p = 0.0026$). For each unit increase in VAS, PRAISE scores increased by an average of 1.0077 units ($\beta = 1.0077$, $p = 0.0056$), indicating a strong positive relationship between VAS and PRAISE. Additionally, high PRAISE was significantly associated with high compliance ($\beta = -0.1616$; OR = 0.8508, $p = 0.0016$).

Abbreviations: VAS, Visual Analog Scale; PRAISE, the Pulmonary Rehabilitation Adapted Index of Self Efficacy.

Assuming PRAISE as a mediator variable for VAS, mediation analysis yielded a statistically significant mediation effect size of -0.1628 (95% CI: -0.7745 to -0.0035 , $p < 0.05$). In addition, after controlling for PRAISE, the impact of VAS on behavioral outcomes remained statistically significant, with a regression coefficient of -0.4309 (95% CI: -0.7110 to -0.1507 , $p < 0.05$). These results suggest that PRAISE acts as a partial mediator in the relationship between VAS and behavioral outcomes (Figure 7).

Discussion

This study, grounded in SCT, assessed the significance of key research variables on discriminative adherence to remotely monitored home-based PR among patients with moderate-to-severe COPD in a stable phase. Notably, it pioneered the development of a four-variable predictive model based on SCT, incorporating PRAISE, OEE, MoCA, and VAS. The model demonstrated high sensitivity and specificity in discriminating the likelihood of successful completion of remote PR programs. It serves as a valuable assessment tool for identifying patients who may be less capable of effectively participating in remote PR sessions. Furthermore, mediation analysis of the predictors revealed that PRAISE was highly likely to mediate the impact of OEE and MoCA on behavioral outcomes. This finding suggests that PRAISE could be a key intervention target to improve remote PR adherence in COPD patients. Therefore, timely implementation of tailored behavioral interventions might help patients with COPD achieve greater benefits from remote PR.

With the rapid development of the Internet and advanced technology, as well as during the global COVID-19, patients have been severely restricted from receiving traditional rehabilitation treatment in the hospital environment. Therefore, telemedicine has been used globally as a new medical service for self-management of chronic respiratory diseases.³⁵ Adopting a low-cost, safe, effective and user-friendly remote home-based rehabilitation and exercise monitoring smartphone App, patients can be provided with a more scientific exercise training program.³⁶ Traditional Chinese exercise regimen, such as Baduanjin, is an excellent heritage of Chinese health preservation culture. After continuous practice involving relaxation and slow movements, Baduanjin exercise can effectively improve the lung function, exercise endurance, and hospitalization frequency of stable COPD patients.³⁷ However, patients with COPD exhibit a relatively high dropout rate during PR treatment, with the specific reasons remaining unclear. Current research in this field has partially focused on demographic characteristics. Patients aged 60 years and older show a higher PR completion rate compared with those under 60.¹³ Cultural differences, marital status, and economic status are also considered factors influencing PR completion rates.³⁸ Brown et al found that smoking at the time of enrollment was associated with a reduced PR completion rate (adjusted odds ratio: 0.38, 95% CI: 0.16–0.90, $p = 0.02$).³⁹ Moreover, clinical and psychological characteristics have been identified as factors linked to PR dropout. These include being underweight or

obese, experiencing severe dyspnea, shorter six-minute walking distance, frequent exacerbations, and elevated levels of anxiety and depression.^{13,38,40,41} Research demonstrates that as little as one month of successful tobacco abstinence yields measurable health improvements. These include enhanced respiratory symptoms and lung function, along with critical metabolic parameter changes such as blood lipid profiles and vitamin D levels.⁴² Preliminary evidence suggests that short-term smoking cessation may improve adherence to PR. This potential effect requires further verification. The presence of a well-developed public medical facility and technical service system is also crucial for ensuring the smooth implementation of PR.⁴³

From a behavioral perspective and based on SCT, this study explored the underlying behavioral factors influencing the choice of remote PR. Among patients with COPD who had similar demographic and disease characteristics, PRAISE, OEE, MoCA, and VAS demonstrated good discriminatory power for the completion of PR, which primarily utilized Baduanjin in remote home settings. Our results showed that PRAISE scores strongly correlate with patient adherence. However, patients with high PRAISE scores may inherently have higher health literacy, rather than directly predicting compliance. PRAISE and OEE scores may not only predict adherence but also indicate that the patient has reached an advanced stage of behavioral change or possesses high health literacy. Thus, the relationship between these variables and adherence is likely bidirectional, not a simple one-way prediction.

PR training, as a behavioral approach to promoting health in patients with COPD, is influenced by a behavioral ecosystem. This ecosystem includes cultural, economic, familial, personal knowledge, and motivational factors. Multiple variables within this system interact at various levels, shaping behavioral patterns.^{12,17,38–41} Understanding the specific mechanisms underlying behavior provides a foundation for influencing or changing these patterns. Within the theoretical framework of behavioral science, identifying key variables that determine behavioral choices for specific actions in particular populations can establish feasible pathways for promoting healthy behavioral patterns.

This study focused on patients with COPD participating in remote PR in our region. After excluding demographic and clinical characteristics previously shown to affect conventional PR completion rates, candidate variables selected based on SCT—including PRAISE, OEE, MoCA, and the VAS score for willingness to receive PR treatment—were better able to explain the reasons for remote PR dropout in this population. Current research has found that intervention through the bystander effect can enhance self-efficacy in patients with COPD during cardiopulmonary exercise testing.⁴⁴ The intervenability of self-efficacy has been methodologically confirmed, suggesting its feasibility as an important target for behavioral interventions aimed at improving PR completion rates.

The interactional determinism theory serves as the core framework of SCT, positing that individual behavior, personal intrinsic factors, and the environment form a dynamic interactive system, thus rejecting unidirectional determinism.^{18,19} This study selected four intrinsic factors derived from this theory—PRAISE, OEE, VAS, and MoCA—to assess their impact on PR behavior in patients with COPD. A cross-sectional survey revealed significant correlations between these factors and rehabilitation adherence. Due to the temporal limitations of cross-sectional designs, these indicators cannot infer causal relationships with PR outcomes. However, despite its exploratory nature, these results provide preliminary evidence for future prospective studies.

This study has some limitations, including a small sample size and the refusal of some patients to participate in the cross-sectional survey, which increases the risk of selection bias. Further multicenter, prospective, large-sample cohort studies are needed for validation. Questionnaires were administered only upon completion or withdrawal from remote PR, resulting in the absence of baseline data collection at enrollment and dynamic monitoring throughout the process. Monitoring trends in related variables may help refine the predictive model and enhance its discriminatory power. The study included only patients with COPD who completed or withdrew from remote PR, excluding those who refused participation. However, previous research indicates no significant differences in behavioral factors between those who refused and those who withdrew.⁴⁵ Moreover, the predictive model was based on a 12-week program, which may be inadequate for reflecting outcomes of longer remote home-based rehabilitation interventions. This study revealed through mediation analysis that PRAISE mediates the effect of cognitive function on PR adherence. Nevertheless, since this conclusion is based solely on cross-sectional rather than longitudinal data, its application to mediation analysis is temporally limited. Finally, the self-report tools used in this study, such as PRAISE, OEE, and VAS, may be affected

by social desirability bias, especially in samples with high motivation. Future research can reduce such biases by combining objective indicators, such as actual compliance data.

Conclusion

Improving and sustaining health-promoting behaviors are primary objectives of PR for patients with COPD. This study focused on examining the behavioral traits that facilitate the successful completion of remote PR programs. Patients with similar demographic and clinical characteristics showed good correlation between their PRAISE, OEE, MoCA, and VAS scores and adherence to PR. These correlations might predict the completion of remote PR in COPD patients. Notably, self-efficacy was associated with the efficacy of remote home-based intervention strategies. Enhancing self-efficacy may encourage the maintenance of beneficial health behaviors, thereby reducing the substantial burden that COPD imposes on patients and society. This cross-sectional exploratory study proposes a preliminary hypothesis: in specific populations or contexts, research indicators (PRAISE, OEE, VAS, and MoCA) that highly correlate with PR adherence may imply causal relationships. However, this model requires prospective validation and further exploration of adherence dynamics over time.

Abbreviations

AUC, area under the curve; CI, confidence interval; COPD, chronic obstructive pulmonary disease; E/F, energy/fatigue; HADS, Hospital Anxiety and Depression Scale; HC, high-completion; LC, low-completion; MH, mental health; MoCA, Montreal Cognitive Assessment; OEE, Outcome Expectations for Exercise Scale; PF, physical functioning; PR, pulmonary rehabilitation; PRAISE, Pulmonary Rehabilitation Adapted Index of Self-Efficacy; REP, role limitations due to emotional problems; RPH, role limitations due to physical health; SCT, social cognitive theory; SF, social functioning; SF-36, Short Form Health Survey; VAS, Visual Analog Scale.

Data Sharing Statement

The data supporting this study's findings will be made available upon reasonable request to the corresponding author.

Ethics Approval and Informed Consent

This study was approved by the Ethics Committee of the First Affiliated Hospital of Nanjing Medical University (Approval No. 2021-SR-024), the Geriatric Hospital of Nanjing Medical University (Approval No. 2021-010), and the Affiliated BenQ Hospital of Nanjing Medical University (Approval No. 2021-KL011). All participants provided informed consent before enrollment.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare no known financial or personal conflicts of interest that could have influenced the research outcomes herein.

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