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Pulmonary Rehabilitation Outcomes According to Employment Status in Individuals with COPD: A Prospective Exploratory Study

Takeshi Yamazaki [1,*], Takumi Nagayama [2], Michiko Tsuchiya [3], Yukio Nagasaka [4], Shota Kotani [5], Kohji Iwai [6], Kunihiko Anami [7] and Jun Horie [1]

[1] Department of Physical Therapy, Faculty of Health Sciences, Kyoto Tachibana University, Kyoto 607-8175, Japan; horie-j@tachibana-u.ac.jp
[2] Department of Rehabilitation, Rakuwakai Otowa Hospital, Kyoto 607-8062, Japan; nagayama-takumi@rakuwa.or.jp
[3] Department of Respiratory Medicine, Rakuwakai Otowa Hospital, Kyoto 607-8062, Japan; tsuchiya-michiko@rakuwa.or.jp
[4] Rakuwakai Academic Support Center, Rakuwakai Otowa Hospital, Kyoto 607-8062, Japan; nagasaka-yukio@rakuwa.or.jp
[5] Faculty of Rehabilitation, Department of Physical Therapy, Kobe International University, Hyogo 658-0032, Japan; kotani@kobe-kiu.ac.jp
[6] Division of Physical Therapy, Faculty of Rehabilitation and Care, Seijoh University, Tokai City 476-8588, Japan; iwai@seijoh-u.ac.jp
[7] Department of Rehabilitation, Faculty of Health and Medical Sciences, Nara Gakuen University, Nara 631-8524, Japan; anami@naragakuen-u.jp
* Correspondence: yamazaki-takes@tachibana-u.ac.jp; Tel.: +81-75-571-1111; Fax: +81-75-574-4122

Abstract

Background and Purpose: As the workforce ages, facilitating the integration of medical care and occupational activities is a key concern for individuals with chronic obstructive pulmonary disease. Although dyspnea is associated with reduced work productivity, the relationship between employment status and the effects of pulmonary rehabilitation remains unclear. This study examined whether changes in exercise capacity and dyspnea following pulmonary rehabilitation differed according to employment status in individuals with chronic obstructive pulmonary disease. **Methods**: This exploratory prospective cohort study included 34 individuals with chronic obstructive pulmonary disease who participated in a 3-month outpatient pulmonary rehabilitation program. Participants were classified as employed (n = 6) or unemployed (n = 28). To evaluate changes following pulmonary rehabilitation, a two-way repeated-measures analysis of covariance (ANCOVA) was performed. Time (pre- and post-intervention) was treated as a within-subject factor, while employment status served as a between-subject factor, with age incorporated as a covariate. The primary endpoints were functional exercise capacity, evaluated using the 6 min walk distance, and dyspnea severity, assessed using the modified Medical Research Council scale. **Results**: For functional exercise capacity, neither the time × employment status interaction nor the main effect of time was statistically significant ($p = 0.165$ and $p = 0.062$, respectively). For dyspnea, the time × employment status interaction was not statistically significant ($p = 0.567$), whereas a significant main effect of time ($p = 0.020$) and a significant time × age interaction ($p = 0.014$) were observed. Exploratory within-group comparisons did not detect significant changes in either employment group. **Discussion**: No statistically significant differences in changes in exercise capacity or dyspnea were detected between employment groups. The significant main effect of time for dyspnea should be interpreted in light of the significant time × age interaction. Given the small and markedly unequal group sizes, particularly the limited number of employed participants, these

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findings should be regarded as exploratory and hypothesis-generating. Larger prospective studies are required to determine whether employment-related factors modify responses to pulmonary rehabilitation.

Keywords: chronic obstructive pulmonary disease; pulmonary rehabilitation; dyspnea; exercise capacity

1. Introduction

Chronic obstructive pulmonary disease (COPD) is a major cause of global morbidity and mortality and is characterized by persistent airflow limitation in conjunction with chronic respiratory symptoms [1]. In addition, patients with COPD frequently experience extrapulmonary manifestations such as skeletal muscle dysfunction and exercise intolerance [2]. Dyspnea is a key clinical feature of COPD and is associated with decreased levels of physical activity as well as deteriorations in quality of life [3]. Reduced physical activity has been identified as an important predictor of hospitalization and mortality in individuals with COPD [4,5]. Furthermore, persistent dyspnea and reduced exercise tolerance often lead to limitations in activities of daily living (ADLs) and social participation, thereby increasing the overall disease burden [6].

Pulmonary rehabilitation (PR) is a comprehensive, multidisciplinary intervention that combines exercise training, education, and behavioral modification strategies to improve the physical and psychological condition of individuals with chronic respiratory diseases [4,7]. It is widely recognized as an effective non-pharmacological treatment that improves functional exercise capacity and alleviates dyspnea in patients with COPD [4,8]. Functional exercise capacity in this population is commonly assessed using the 6-min walk distance (6MWD), which is considered a valid, reliable, and clinically meaningful outcome measure [9]. Previous systematic reviews and meta-analyses have consistently demonstrated that PR contributes to improvements in exercise tolerance and health-related quality of life and reductions in dyspnea among individuals with COPD [8]. However, the magnitude of improvement following PR varies substantially among individuals, suggesting that social and lifestyle-related factors may influence rehabilitation outcomes [10].

In recent years, increasing attention has been directed toward the social consequences of COPD, particularly work participation and productivity. COPD imposes a considerable socioeconomic burden through work absenteeism, presenteeism, and premature withdrawal from employment [11,12]. Dyspnea and reduced physical functioning have been associated with impaired work productivity and increased presenteeism among employed individuals with respiratory diseases [13]. Maintaining employment is important not only from an economic perspective but also to preserve social roles, self-efficacy, and quality of life among patients with chronic diseases [14]. Nevertheless, individuals with COPD who remain employed may differ from unemployed individuals in baseline physical activity levels, daily activity demands, and symptom perception, all of which may influence their responsiveness to PR.

Employment status represents an important dimension of social and occupational participation; however, it should not be considered a direct surrogate for habitual physical activity. Employed and unemployed individuals may differ in occupational demands, functional reserve, disease severity, socioeconomic characteristics, and daily activity patterns, any of which could potentially influence rehabilitation outcomes.

Despite the growing recognition of work-related outcomes in COPD, little is known about whether employment status influences the effectiveness of PR. Clarifying this rela-

tionship may provide useful insights for developing individualized rehabilitation strategies that consider patients' social backgrounds and occupational participation. Therefore, this prospective cohort study was designed to compare changes in exercise capacity and dyspnea before and after a standardized pulmonary rehabilitation program according to employment status in individuals with COPD. A prospective pre–post design was selected because it enables direct evaluation of individual responses to rehabilitation while minimizing the influence of between-subject variability. Given the limited evidence regarding employment status and PR responsiveness, the analysis was considered exploratory.

2. Methods

2.1. Participants and Covariates

This prospective cohort study was conducted between 1 April 2021, and 31 March 2025, and enrolled 34 individuals diagnosed with COPD who were scheduled to participate in a 3-month outpatient PR program during this period. Participants were recruited consecutively. Individuals were excluded if they presented with severe comorbid conditions unrelated to the respiratory system, limitations in ambulation, or marked cognitive impairment.

The sample size was determined a priori using G*Power software (version 3.1.9.7; Heinrich-Heine University Düsseldorf, Düsseldorf, Germany) based on a repeated-measures analysis of variance (ANOVA) with a within–between interaction design [15,16]. Assuming an effect size of $f = 0.25$, $\alpha = 0.05$, power $(1 - \beta) = 0.80$, two groups, two measurements, a within-subject correlation of 0.50, and a nonsphericity correction of $\varepsilon = 1$, the estimated sample size was 34 participants, with an assumed balanced allocation of 17 participants per group. Although the total target sample size was achieved, the observed distribution was markedly unequal (6 employed and 28 unemployed participants). Therefore, the assumptions underlying the original power calculation were not fulfilled, particularly for detecting the time × employment status interaction. Accordingly, analyses involving employment status were interpreted as exploratory.

At baseline, participants were categorized into employed and unemployed groups according to their occupational status. Employment was operationally defined as engagement in paid work. Prior to the intervention, demographic data, pulmonary function indices, and clinical variables were collected. Exercise capacity and dyspnea were evaluated both before and after completion of the PR program. A flow diagram illustrating participant progression throughout the study is presented in Figure 1. To account for potential participant dropout, the study was initiated with 36 patients.

2.2. Pulmonary Rehabilitation Program

All participants underwent a 3-month outpatient pulmonary rehabilitation (PR) program at Rakuwakai Otowa Hospital. The program was scheduled once weekly, with each session lasting approximately 40 min, for a total of 12 scheduled sessions. The program was supervised by physiotherapists and included aerobic exercise, resistance training, breathing exercises, and individualized patient education.

Aerobic exercise was performed using a cycle ergometer. Exercise intensity was individually prescribed using the modified Borg scale, targeting a perceived exertion level ranging from light to moderate. The Borg scale was used to facilitate patients' understanding of exercise intensity and promote self-management. Resistance training targeted the upper and lower extremities according to individual needs, with particular emphasis on the lower extremities. Exercise intensity and progression were adjusted in consultation with a respiratory physician according to each participant's exercise tolerance and clinical condition.

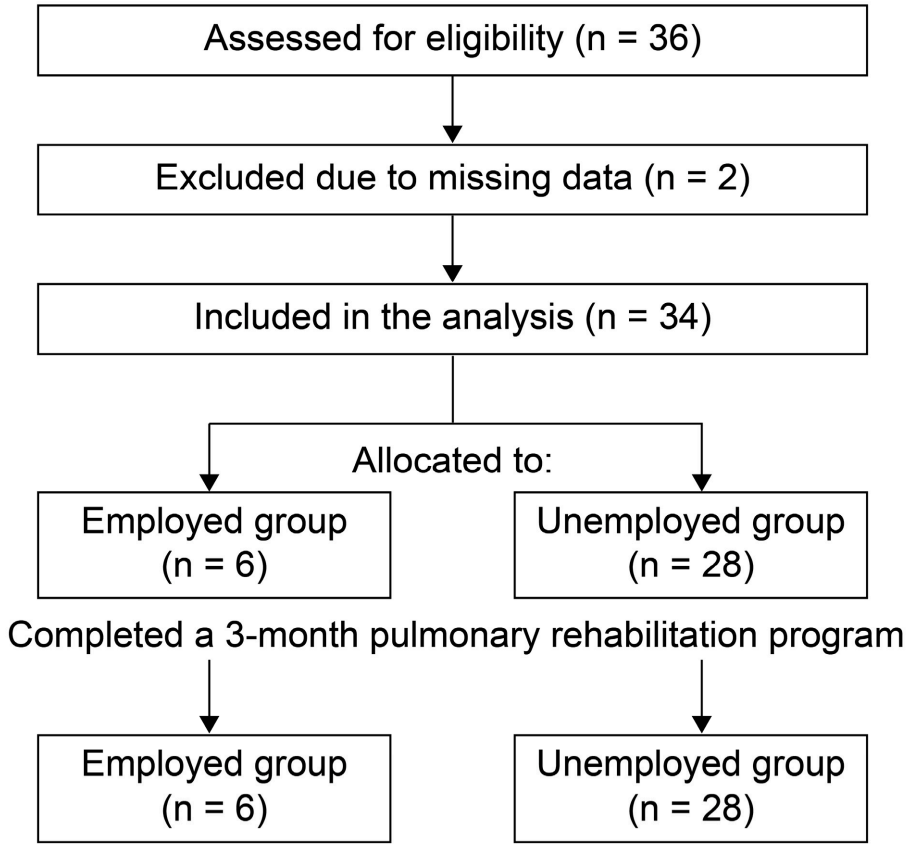


Figure 1. Flow diagram of study participants.

Breathing exercises included instruction in pursed-lip breathing. Individualized guidance on activities of daily living (ADL) was provided based on the Nagasaki University Respiratory Disease ADL Questionnaire (NRADL), focusing on activities for which participants had lower scores. Patient education was delivered face-to-face and included guidance on symptom management and ADL performance.

To promote self-management, participants were instructed to record their respiratory condition in a respiratory management handbook. These records were reviewed and discussed with physiotherapists during weekly sessions. In addition, individualized home exercise sheets were prepared and provided to participants to support independent exercise outside the supervised sessions.

2.3. 6-Min Walk Test

The 6-min walk test (6MWT) was administered following the standardized protocol established by the American Thoracic Society [9]. The distance achieved during the test (6MWD) is widely used as a simple indicator of functional exercise capacity in patients with chronic respiratory diseases and has been established as a valid and reliable marker of exercise performance.

2.4. Assessment of Dyspnea

Perceived breathlessness in daily life was quantified using the modified Medical Research Council (mMRC) scale, which ranges from 0 to 4 [17]. In addition, dyspnea associated with activities of daily living (ADLs) was evaluated using the Nagasaki University Respiratory Disease ADL Questionnaire (NRADL; score range: 0–100). Exercise-induced dyspnea was measured during the 6MWT with the modified Borg scale (0–10).

2.5. Assessment of COPD-Specific Health Status

Participants' COPD-specific health status was evaluated using the COPD Assessment Test (CAT). It is a validated, self-administered questionnaire consisting of eight items that are used to assess the impact of COPD on a patient's health status, including cough, sputum production, chest tightness, breathlessness, activity limitation, confidence, sleep, and energy levels. Each item is scored from 0 to 5, yielding a total score ranging from 0 to 40, higher scores indicating a greater symptom burden and poorer health-related quality of life [18].

2.6. Assessment of Disease Severity

Disease severity was assessed using the BODE index, a multidimensional grading system that incorporates body mass index, airflow obstruction, dyspnea, and exercise capacity. Airflow obstruction was evaluated using the percent predicted forced expiratory volume in one second, dyspnea was assessed using the mMRC scale, and exercise capacity was measured using the 6MWD. The BODE index score ranges from 0 to 10, higher scores reflecting greater disease severity and a poorer prognosis [19].

2.7. Assessment of ADLs

ADLs were evaluated using the NRADL. This instrument comprises four domains with a maximum total score of 100 points, including movement speed, dyspnea, and oxygen flow (each allocated 30 points), as well as continuous walking distance (10 points). The NRADL enables a comprehensive evaluation of how dyspnea influences daily functioning and has been reported to exhibit strong reliability and sensitivity to changes following PR [20].

The NRADL was used in accordance with the explanation in the original publication [20]. No additional permission from the original developers or copyright holders was required for its use in this study.

2.8. Muscle Strength Evaluation

Handgrip strength was assessed with a digital dynamometer (Takei Scientific Instruments Co., Niigata, Japan), with participants in the standing position and measurements obtained from the dominant hand. Knee extensor strength was assessed in a seated posture via a handheld dynamometer (Anima Co., Tokyo, Japan). For both outcomes, measurements were performed twice on each side, and the maximum value was adopted for subsequent analyses.

To account for individual body size, knee extensor strength was normalized to body weight by calculating joint torque. Torque was derived as the product of the measured force and the distance between the knee joint axis and the point of force application. Prior to testing, participants were instructed to remain relaxed, and two trials were conducted. Adequate rest intervals were provided between trials to reduce the potential influence of fatigue.

2.9. Statistical Analysis

Data analyses were performed using IBM SPSS Statistics for Windows (version 27.0; IBM Corp., Armonk, NY, USA). Prior to statistical testing, the distribution of each variable was examined to verify normality. Comparisons between groups were performed using independent *t*-tests for continuous variables and chi-square analyses for categorical variables.

To evaluate the effects of PR, a two-way repeated-measures analysis of covariance (ANCOVA) was performed, incorporating time (pre- and post-intervention) as the within-subject factor and employment status as the between-subject factor, with age included as a covariate. The time × employment status interaction was examined to determine whether changes in outcomes differed between the groups. The main effect of time was

also evaluated. Exploratory within-group comparisons were conducted using estimated marginal means without adjustment for multiple comparisons. These comparisons were not used to infer differences in rehabilitation responses between the employment groups.

The same analytical framework was extended to secondary outcome measures. Effect sizes for pre–post changes were calculated using Cohen's d, defined as the difference between the post-intervention and pre-intervention means divided by the pooled standard deviation of the two measurements: $d = (Mpost - Mpre)/\sqrt{[(SDpre^2 + SDpost^2)/2]}$, where Mpre and Mpost represent the pre- and post-intervention means, respectively, and SDpre and SDpost represent their corresponding standard deviations. Positive and negative values indicate increases and decreases, respectively. These effect sizes were calculated from the descriptive statistics and were not derived from the age-adjusted ANCOVA estimates. Statistical significance was defined as a p-value < 0.05.

2.10. Incomplete Data

Some outcome measures were not available for all participants because pre- and/or post-intervention assessments were incomplete. Incomplete data were observed for the 6-min walk distance (6MWD), modified Medical Research Council (mMRC) dyspnea scale, skeletal muscle mass index, COPD Assessment Test (CAT), BODE index, knee extensor strength, and Nagasaki University Respiratory Disease ADL Questionnaire (NRADL). Analyses for each outcome were conducted using available-case data, and the corresponding sample sizes are reported in the tables. Missing values occurred because some participants were unable to complete specific assessments or because measurement data were unavailable. No imputation procedures were performed. Statistical analyses were conducted using available-case analysis, whereby participants with missing data for a given variable were excluded only from analyses involving that variable.

3. Results

Among the 34 participants, 6 were categorized as employed and 28 as unemployed. Participant baseline characteristics are presented in Table 1. At baseline, no significant between-group differences were found in age, body mass index, pulmonary function measures other than forced vital capacity (FVC), or comorbidity indices. At baseline, the employed group had a significantly higher percent predicted FVC and significantly lower CAT and BODE index scores than the unemployed group ($p = 0.002$, $p = 0.045$, and $p = 0.027$, respectively).

The effects of PR on the primary outcomes are presented in Table 2, and corresponding changes are illustrated in Figure 2. For the 6MWD, neither the time × employment status interaction nor the main effect of time was statistically significant ($p = 0.165$ and $p = 0.062$, respectively). Exploratory within-group comparisons showed a significant increase in the 6MWD in the unemployed group ($p < 0.001$), whereas no significant change was detected in the employed group ($p = 0.946$).

For dyspnea severity assessed using the mMRC scale, no significant time × employment status interaction was observed ($p = 0.567$), whereas a significant main effect of time was identified ($p = 0.020$). A significant time × age interaction was also observed ($p = 0.014$). Exploratory within-group comparisons did not detect statistically significant changes in either the employed group ($p = 0.318$) or the unemployed group ($p = 0.493$).

The impact of PR on secondary outcomes is summarized in Table 3. No statistically significant time × employment status interactions or main effects of time were observed for any of the secondary outcomes. Exploratory within-group comparisons showed a significant increase in knee extensor strength in the unemployed group ($p = 0.044$). No other statistically significant within-group changes were detected.

Table 1. Baseline Characteristics of the Participants.

Variable	Employed Group (n = 6)	Unemployed Group (n = 28)	Test Statistic	*p*-Value	Effect Size (d/φ)
Age (years)	73.3 ± 6	75.0 ± 9.2	t = 0.423	0.675	0.149
Male sex, n (%)	6 (100)	26(92.9)	χ = 0.705	0.547	0.144
Height (cm)	167.2 ± 5.4	165.9 ± 6.0	t = −0.492	0.626	−0.174
Body weight (kg)	64.0 ± 13.8	57.5 ± 10.4	t = −1.319	0.197	−0.466
Body mass index (kg/m^2)	23.0 ± 5.5	20.8 ± 3.1	t = −0.949	0.381	−0.795
Skeletal muscle mass index (kg/m^2)	7.0 ± 0.9	6.7 ± 1.1	t = −0.538	0.595	−0.200
Charlson Comorbidity Index (points)	2.2 ± 1.9	2.1 ± 1.1	t = −0.102	0.919	−0.036
FEV_1 (L)	1.8 ± 0.5	1.4 ± 0.6	t = −1.498	0.144	−0.538
FEV_1/FVC (%)	56.8 ± 17.6	43.4 ± 4.1	t = −0.635	0.530	−0.228
FEV_1 (% predicted)	67.8 ± 22.3	54.8 ± 20.8	t = −1.372	0.180	−0.492
FVC (% predicted)	94.6 ± 4.9	82.1 ± 15.0	t = −3.522	0.002	−1.382
mMRC dyspnea scale (0–4)	1.5 ± 0.8	2.1 ± 1.0	t = 1.366	0.183	0.516
CAT (points)	11.0 ± 5.3	17.3 ± 8.8	t = 2.206	0.045	1.197
GOLD category (A/B/E)	1/5/0	6/16/4	χ = 1.368	0.505	0.210
BODE index (points)	2.0 ± 1.5	4.1 ± 1.6	t = 2.426	0.027	1.199
Handgrip strength (kg)	32.7 ± 7.8	31.1 ± 7.8	t = −0.444	0.670	−0.157
Knee extensor strength (Nm/kg)	1.10 ± 0.48	1.13 ± 0.33	t = 0.162	0.877	0.073
NRADL (points)	85.5 ± 10.9	77.6 ± 12.9	t = −1.389	0.175	−0.498
6-min walk distance (m)	397.8 ± 63.7	301.9 ± 117.9	t = −1.919	0.064	−0.679

Data are presented as mean ± standard deviation unless otherwise indicated. Categorical variables are presented as number (percentage) or distribution. Comparisons between the employed and unemployed groups were performed using independent-samples *t*-tests for continuous variables and Pearson's chi-square tests for categorical variables. Effect sizes are reported as Cohen's d for continuous variables and φ coefficient (or Cramer's V for variables with more than two categories) for categorical variables. indicates the *p*-value from the chi-square test, and indicates the effect size (φ) from the chi-square test. BODE, body mass index, airflow obstruction, dyspnea, and exercise capacity; CAT, COPD Assessment Test; FEV1, forced expiratory volume in 1 s; FVC, forced vital capacity; GOLD, Global Initiative for Chronic Obstructive Lung Disease; mMRC, modified Medical Research Council; NRADL, Nagasaki University Respiratory Disease Activities of Daily Living Questionnaire. While the difference did not reach statistical significance, exercise capacity, assessed via the 6MWD, was greater in the employed group than that in the unemployed group (397.8 m vs. 301.9 m, $p = 0.064$). A similar pattern was observed for dyspnea severity, measured using the mMRC scale, with lower values in the employed group; however, this difference was not statistically significant.

Table 2. Effects of Pulmonary Rehabilitation on Primary Outcomes.

Outcome	Group	Pre	Post	Test Statistic	Within-Group *p*-Value	Effect Size (d)
6MWD (m)	Employed group (n = 5)	397.8 ± 63.7	409.8 ± 72.0	F = 0.005	0.946	0.177
	Unemployed group (n = 26)	301.9 ± 117.9	338.2 ± 132.7	F = 13.735	<0.001	0.289
	Interaction (time × group)	not applicable	not applicable	F = 2.031	0.165	not applicable
	Main effect (time)	not applicable	not applicable	F = 3.781	0.062	not applicable
mMRC dyspnea scale (0–4)	Employed group (n = 6)	1.5 ± 0.8	1.3 ± 0.5	F = 1.037	0.318	−0.300
	Unemployed group (n = 22)	2.1 ± 1.0	1.9 ± 1.1	F = 0.485	0.493	−0.190
	Interaction (time × group)	not applicable	not applicable	F = 0.337	0.567	not applicable
	Main effect (time)	not applicable	not applicable	F = 6.198	0.020	not applicable

Data are presented as mean ± standard deviation. Changes in outcomes were evaluated using two-way repeated-measures analysis of covariance (ANCOVA), with time (pre- and post-intervention) as the within-subject factor, employment status (employed and unemployed) as the between-subject factor, and age as a covariate. Interaction effects (time × employment status) and main effects of time are presented as F statistics and corresponding *p*-values. Exploratory within-group comparisons were conducted using estimated marginal means without adjustment for multiple comparisons. Effect sizes are reported as Cohen's d and were calculated as the difference between the post-intervention and pre-intervention means divided by the pooled standard deviation of the two measurements: $d = (Mpost - Mpre)/\sqrt{[(SDpre^2 + SDpost^2)/2]}$. Effect sizes were calculated from the descriptive statistics and were not derived from the age-adjusted ANCOVA estimates. Sample sizes vary across outcome measures because participants with incomplete pre- or post-intervention measurements were excluded from the analysis of the corresponding outcome.

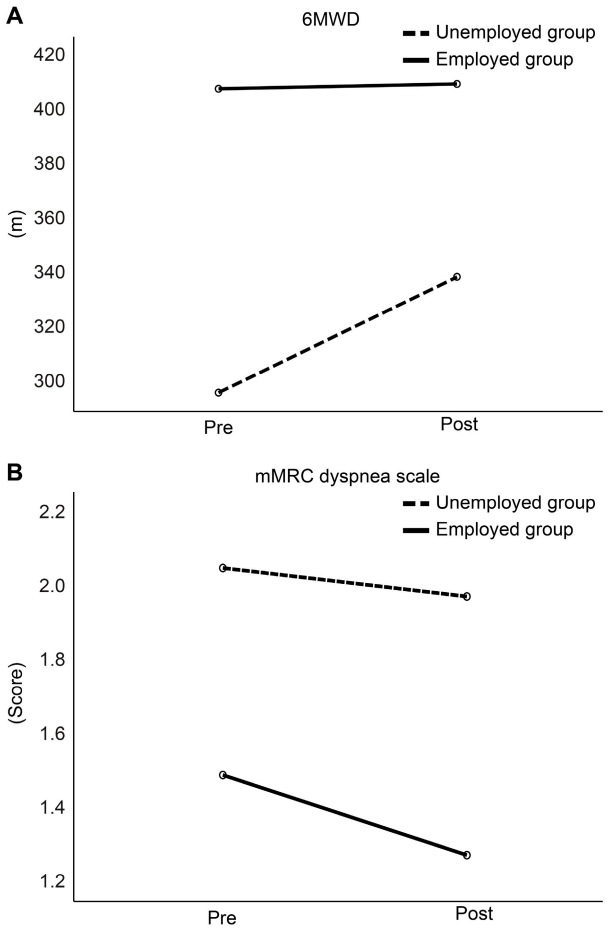


Figure 2. Changes in primary outcomes following pulmonary rehabilitation according to employment status. (**A**) 6MWD and (**B**) mMRC dyspnea scale score.

Table 3. Effects of Pulmonary Rehabilitation on Secondary Outcomes.

Outcome	Group	Pre	Post	Test Statistic	Within-Group *p*-Value	Effect Size (d)
Skeletal muscle mass index (kg/m^2)	Employed group (n = 6)	7.0 ± 0.9	7.0 ± 0.8	F = 0.041	0.840	0.000
	Unemployed group (n = 22)	6.7 ± 1.1	6.5 ± 1.1	F = 0.887	0.355	−0.182
	Interaction (time × group)	not applicable	not applicable	F = 0.065	0.801	not applicable
	Main effect (time)	not applicable	not applicable	F = 0.059	0.810	not applicable
CAT (points)	Employed group (n = 5)	11.0 ± 5.3	8.4 ± 3.4	F = 2.146	0.157	−0.584
	Unemployed group (n = 20)	17.3 ± 8.8	15.0 ± 9.9	F = 2.108	0.161	−0.246
	Interaction (time × group)	not applicable	not applicable	F = 0.442	0.513	not applicable
	Main effect (time)	not applicable	not applicable	F = 2.199	0.152	not applicable
BODE index (points)	Employed group (n = 6)	2.0 ± 1.5	1.5 ± 1.8	F = 1.996	0.171	−0.302
	Unemployed group (n = 21)	4.2 ± 3.1	3.7 ± 3.0	F = 0.816	0.375	−0.164
	Interaction (time × group)	not applicable	not applicable	F = 0.673	0.420	not applicable
	Main effect (time)	not applicable	not applicable	F = 2.589	0.121	not applicable

Table 3. *Cont.*

Outcome	Group	Pre	Post	Test Statistic	Within-Group *p*-Value	Effect Size (d)
Handgrip strength (kg)	Employed group (n = 6)	32.7 ± 7.8	32.1 ± 8.6	F = 0.113	0.739	−0.073
	Unemployed group (n = 28)	31.1 ± 7.8	31.2 ± 8.1	F = 0.000	0.997	0.013
	Interaction (time × group)	not applicable	not applicable	F = 0.093	0.763	not applicable
	Main effect (time)	not applicable	not applicable	F = 0.169	0.684	not applicable
Knee extensor strength (Nm/kg)	Employed group (n = 6)	1.10 ± 0.48	0.98 ± 0.53	F = 0.599	0.445	−0.237
	Unemployed group (n = 26)	1.13 ± 0.33	1.29 ± 0.47	F = 4.456	0.044	0.394
	Interaction (time × group)	not applicable	not applicable	F = 2.595	0.118	not applicable
	Main effect (time)	not applicable	not applicable	F = 1.760	0.195	not applicable
NRADL (points)	Employed group (n = 5)	85.5 ± 10.9	91.2 ± 7.0	F = 0.968	0.334	0.622
	Unemployed group (n = 24)	77.6 ± 12.9	80.8 ± 19.4	F = 0.387	0.539	0.194
	Interaction (time × group)	not applicable	not applicable	F = 0.406	0.530	not applicable
	Main effect (time)	not applicable	not applicable	F = 0.261	0.614	not applicable

Data are presented as mean ± standard deviation. Changes in outcomes were evaluated using two-way repeated-measures analysis of covariance (ANCOVA), with time (pre- and post-intervention) as the within-subject factor, employment status (employed and unemployed) as the between-subject factor, and age as a covariate. Interaction effects (time × employment status) and main effects of time are presented as F statistics and corresponding *p*-values. Exploratory within-group comparisons were conducted using estimated marginal means without adjustment for multiple comparisons. Effect sizes are reported as Cohen's d and were calculated as the difference between the post-intervention and pre-intervention means divided by the pooled standard deviation of the two measurements: $d = (Mpost - Mpre)/\sqrt{[(SDpre^2 + SDpost^2)/2]}$. Effect sizes were calculated from the descriptive statistics and were not derived from the age-adjusted ANCOVA estimates. Sample sizes vary across outcome measures because participants with incomplete pre- or post-intervention measurements were excluded from the analysis of the corresponding outcome. BODE, body mass index, airflow obstruction, dyspnea, and exercise capacity; CAT, COPD Assessment Test; NRADL, Nagasaki University Respiratory Disease Activities of Daily Living Questionnaire.

4. Discussion

This prospective cohort study addressed the previously unexplored question of whether employment status modifies the response to pulmonary rehabilitation in individuals with COPD. The principal finding was that no statistically significant time × employment status interaction was detected for either exercise capacity or dyspnea. Although exploratory within-group comparisons showed a significant increase in the 6MWD in the unemployed group, this finding does not establish a difference in rehabilitation responses between employment groups. A significant main effect of time was observed for dyspnea, although a significant time × age interaction was also identified. These findings provide preliminary evidence regarding the relationship between employment status and PR outcomes and highlight the need for further investigation of occupational factors in rehabilitation research. From a clinical perspective, occupational participation may be considered when establishing individualized rehabilitation goals, although the present findings do not demonstrate that employment status modifies rehabilitation effectiveness.

A significant main effect of time was observed for dyspnea, although exploratory within-group comparisons did not identify statistically significant changes in either employment group. Previous meta-analyses have demonstrated that PR can improve exercise capacity and health-related quality of life in individuals with COPD [8,21]. The mechanisms underlying dyspnea relief after PR are considered to involve a combination of

physiological and functional adaptations; however, these processes were not directly examined in the present study. Accordingly, the observed reduction in dyspnea should be interpreted with caution when considered as a clinical endpoint. Furthermore, the significant time × age interaction suggests that changes in dyspnea may vary with age. Therefore, the findings should not be interpreted as demonstrating uniform dyspnea improvement across participants or as establishing that employment status has no influence on rehabilitation responses.

COPD has been recognized as a condition that significantly impacts work ability and functional independence [14]. For exercise capacity, neither the main effect of time nor the time × employment status interaction was statistically significant. Nevertheless, exploratory within-group comparisons identified a significant increase in the 6MWD in the unemployed group, whereas no significant change was detected in the employed group. Importantly, a significant within-group change in one group and a nonsignificant change in another do not establish a statistically significant difference in rehabilitation responses between groups. One possible explanation is a ceiling effect, as the employed group exhibited higher baseline 6MWDs. Previous studies have demonstrated that baseline functional status strongly influences responsiveness to PR, with greater improvements observed in individuals with lower initial exercise capacities [7,22]. However, the present study did not directly examine whether baseline exercise capacity modified rehabilitation responses. Furthermore, COPD is a heterogeneous disease, and clinical phenotypes, baseline disease severity, and systemic involvement may contribute to differences in functional status. Previous research has highlighted associations between a history of pulmonary tuberculosis and COPD severity, while a recent narrative review has discussed the clinical characteristics and systemic involvement of tuberculosis-associated COPD [23,24]. Although these findings underscore the importance of considering disease heterogeneity, the present study did not assess tuberculosis history or examine phenotype-specific responses to PR. Therefore, the possible ceiling effect and the contributions of disease heterogeneity should be regarded as hypotheses requiring further investigation rather than established explanations for the observed findings.

Employment status may reflect differences in daily routines, occupational demands, and opportunities for physical activity. However, employment status should not be regarded as a direct indicator of habitual physical activity. Because objectively measured physical activity and occupational physical demands were not assessed in the present study, it is not possible to determine whether these factors contributed to the observed changes in exercise capacity. Previous studies have shown that physical activity levels are closely associated with clinical outcomes in patients with COPD [5,10,25]. Future studies incorporating objective physical activity measurements and detailed occupational information are needed to examine these potential relationships.

The findings raise questions regarding the relationship between exercise capacity and dyspnea following PR. A significant main effect of time was observed for mMRC, whereas the corresponding main effect for the 6MWD was not statistically significant. However, these findings alone do not establish a dissociation between functional capacity and symptom perception, particularly because the relationship between individual changes in these outcomes was not directly examined.

PR involves multiple components targeting physical function and symptoms [4]. Moreover, contemporary COPD assessment recognizes the importance of considering multiple dimensions of the disease rather than relying on a single physiological measure [26]. Accordingly, the present findings support the continued assessment of both exercise capacity and dyspnea, while further research is required to clarify their relationships following rehabilitation.

From a clinical perspective, these findings raise questions about how PR outcomes may relate to work participation among patients with COPD. Dyspnea has been identified as a key determinant of reduced work productivity and presenteeism [13,14]. However, the present study did not assess work productivity, occupational performance, or employment retention after PR. Therefore, the present study cannot establish whether changes in dyspnea or exercise capacity translated into improved work-related outcomes. Incorporating occupational goals, dyspnea management, pacing, and individualized activity modification into rehabilitation planning may be relevant for patients who wish to continue working. However, the effectiveness of these approaches for maintaining employment requires direct evaluation in future studies.

Some limitations should be acknowledged when interpreting the results of this study. First, although the sample size was determined a priori before study initiation, the overall number of participants was modest, with a particularly small number in the employed group (n = 6), which may have limited the statistical power to detect interaction effects. Moreover, the unequal distribution of participants between groups could have affected the analytical results. The number of participants included in individual outcome analyses was further reduced by missing measurements. Consequently, the absence of statistically significant interactions should not be interpreted as evidence that rehabilitation responses were equivalent between the groups.

Second, despite the prospective cohort framework, this study remains observational, and thus causal inferences cannot be firmly established. In addition, the absence of a non-PR control group prevents changes during the study period from being attributed exclusively to PR. Furthermore, potential confounders that were not captured—such as occupational characteristics, physical job demands, and socioeconomic factors—may have influenced the observed outcomes. Habitual physical activity was also not objectively measured. In addition, although all participants were scheduled to attend 12 PR sessions, actual attendance rates were not systematically recorded or compared between the employment groups. Therefore, potential differences in PR exposure could not be evaluated, and their influence on the observed outcomes remains unclear.

Third, pre-existing differences in exercise capacity between groups may have contributed to a ceiling effect. Although statistical adjustment for age was performed, the possibility of residual confounding cannot be ruled out. Furthermore, the significant time × age interaction for mMRC suggests that age-related variation in dyspnea changes warrants further investigation. The small sample size limited the ability to characterize this relationship in detail.

Fourth, the unemployed group likely comprised a heterogeneous population, including individuals who were no longer working due to age-related retirement rather than disease severity. This heterogeneity may complicate the interpretation of employment status as an indicator of social participation. Furthermore, the dichotomous classification of employment status did not capture differences in occupational demands, working hours, or reasons for unemployment.

Fifth, exploratory within-group comparisons were conducted without adjustment for multiple comparisons, and several outcomes were evaluated. Therefore, isolated statistically significant findings, including the increase in knee extensor strength in the unemployed group, should be interpreted cautiously. In addition, analyses were conducted using participants with available pre- and post-intervention measurements for each outcome, and the potential influence of missing data cannot be excluded.

Finally, because the study was performed at a single outpatient PR facility, the generalizability of the results may be restricted. Considering the modest sample size and the unequal distribution of participants between groups, the findings of this study should be

interpreted as exploratory and as hypothesis-generating rather than confirmatory; further larger, well-designed prospective investigations are required to substantiate these observations. Future studies should also incorporate detailed occupational information, objective physical activity measurements, and work-related outcomes.

In conclusion, no statistically significant time × employment status interactions were detected for exercise capacity or dyspnea following PR in individuals with COPD. Although an exploratory within-group analysis showed a significant increase in the 6MWD in the unemployed group, this finding does not establish a differential rehabilitation response according to employment status. A significant main effect of time was observed for dyspnea, accompanied by a significant time × age interaction.

These findings should be interpreted cautiously because of the small and unequal group sizes. Further studies are needed to clarify the relationships among employment status, rehabilitation outcomes, and occupational participation in individuals with COPD.

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