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Original

FUNCIÓN PULMONAR EN MUJERES POST-COVID-19: UN ENSAYO ALEATORIZADO SOBRE ENTRENAMIENTO EN CIRCUITO CON EJERCICIOS AERÓBICOS, DE FUERZA Y RESPIRATORIOS

PULMONARY FUNCTION IN POST-COVID-19 WOMEN: A RANDOMIZED TRIAL ON CIRCUIT TRAINING WITH AEROBIC, STRENGTH AND BREATHING EXERCISE

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RESUMEN

Objetivos: Si bien la mayoría de los pacientes con la enfermedad por el virus de la corona (COVID-19) se recuperan sin efectos a largo plazo, algunos experimentan síndromes posteriores a la COVID-19 que causan deficiencias físicas persistentes, incluida una función pulmonar reducida. Este estudio tiene como objetivo evaluar los efectos del entrenamiento en circuito que incluye ejercicios aeróbicos, de fortalecimiento y respiratorios sobre la función pulmonar en mujeres con síndromes post-COVID-19.

Métodos: Este ensayo controlado aleatorio incluyó a 60 mujeres con síntomas posteriores a COVID-19, asignadas a ejercicios de control o de 8 semanas, tres veces por semana, de 50 minutos al 65-75% de la frecuencia cardíaca máxima. Las funciones pulmonares y la saturación de oxígeno se midieron utilizando el espirómetro COSMED Pony antes y después del programa. Se utilizó ANOVA de medidas repetidas de parcela dividida para calcular los efectos de tiempo, tratamiento e interacción, seguido de cálculos del tamaño del efecto con la prueba de Cohen. **Resultados:** Se encontraron efectos significativos en el tiempo para todas las medidas, excepto para la saturación de oxígeno (SpO2) y volumen tidal. Los efectos de interacción se demostraron en SpO2, FEV1 (volumen espiratorio forzado en 1 segundo), FEV1/FVC (capacidad vital forzada) y flujo espiratorio máximo (PEF), lo que indica que las mejoras solo ocurrieron en el grupo de tratamiento. El cálculo del tamaño del efecto indicó mejoras significativas en todas las medidas, excluyendo FEV1/FVC% y el volumen tidal en el grupo de ejercicio, mientras que en el grupo de control solo se observaron en FVC y MVV. **Discusión**: El programa de ejercicios mostró claros beneficios para mejorar la función respiratoria en pacientes post-COVID-19. **Conclusión:** Este estudio destaca la efectividad del ejercicio para mejorar la función pulmonar post-COVID-19.

Palabras clave: ejercicio, respiración, concurrente, función pulmonar, espirometría, síndrome posagudo de COVID-19

PULMONARY FUNCTION IN POST-COVID-19 WOMEN: A RANDOMIZED TRIAL ON CIRCUIT TRAINING WITH AEROBIC, STRENGTH AND BREATHING EXERCISE

ABSTRACT

Objectives: While most Corona Virus Disease (COVID-19) patients recover without long-term effects, some experience post-COVID-19 syndromes causing persistent physical impairments, including reduced pulmonary function. This study assesses the effects of circuit training involving aerobic, strength and breathing exercises on pulmonary function in women with post-COVID-19 syndromes. **Methods:** This randomized controlled trial included 60 women with post-COVID-19 symptoms, assigned to control or an 8-week, thrice-weekly, 50-minute exercises at 65-75% maximum heart rate. Pulmonary functions and oxygens saturation were measured using COSMED Pony spirometer before and after the program. Split-plot Repeated Measures ANOVA was used to calculate the time, treatment, and interaction effects, followed by effect size calculations with the Cohens'd. **Results:** Significant time effects for all measures were found, except for SpO2 (oxygen saturation) and tidal volume. Interaction effects were demonstrated in SpO2, FEV1(Force expiratory volume) 1, FEV1/FVC (Forced Vital Capacity) and Peak Expiratory Flow (PEF), indicating that improvements only occurred in the treatment group. Effect size calculation indicated significant improvements in all measures, excluding FEV1/FVC% and tidal volume in the exercise group, while only in FVC and MVV in the control group. **Discussion:** The exercise program showed clear benefits for enhancing overall respiratory function in post-COVID-19 patients. **Conclusion:** This study highlights the effectiveness of the exercise in improving post-COVID-19 pulmonary function.

Keywords: exercise, breathing, circuit training, pulmonary function, spirometry, post-acute COVID-19 syndrome

Journal of Sport and Health Research 2025, 17(2):155-167

INTRODUCTION

The Coronavirus Disease (COVID-19) pandemic has placed unprecedented strains on social, economic, and healthcare systems worldwide (Pillay & Barnes, 2020). A recent report estimates 14.83 million global excess deaths attributed to COVID-19 in 2020-2021, which is 2.74 times higher than reported COVID-19 deaths, emphasizing the profound impact of the pandemic (Msemburi et al., 2023). Notably, beyond the acute phase, a significant majority of patients, over 70%, may experience post-COVID-19 syndrome or long COVID-19, with effects persisting for up to 4 months (Ruggiero et al., 2022), which further exacerbates the burden on the healthcare systems. Therefore, concerted efforts must be made to address the immediate challenges of COVID-19 and its long-term implications.

People positively tested for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) may experience myriad clinical manifestations ranging from fatigue, breathlessness, and muscle discomfort to more severe manifestations like heart irregularities, cognitive impairment, and chest discomfort (Wittmer et al., 2021). More than 50% experience chronic fatigue, shortness of breath, chest pain, and anosmia (Moreno-Pérez et al., 2021). The symptoms can also include reduced oxygen saturation and pneumonia (Jin et al., 2020). Post-COVID-19 syndrome, on the other hand, is defined as cases in which the symptoms persist for 4 to 12 weeks (Fernández-de-Las-Peñas et al., 2021), or months (Koc et al., 2022), beyond the acute stage (Davis et al., 2023; Fernández-de-Las-Peñas et al., 2021). The most commonly reported persistent symptoms are chronic fatigue and shortness of breath, accounting for more than 80% of cases (Koc et al., 2022). Most patients with post-COVID-19 syndrome are outpatients with moderate acute illnesses (Davis et al., 2023). Those with post-COVID-19 syndrome require regular monitoring to ensure their recovery.

Pulmonary function assessments are essential in evaluating and following patients with respiratory diseases, including those with post-COVID-19 syndrome. The three primary measurements of pulmonary functions are volume, time, and flow (Moore, 2012). The pulmonary function assessment aims to assess respiratory airways, pulmonary parenchyma, as well as the size and integrity of the pulmonary capillary bed (Moore, 2012). Although the assessment often does not directly provide a diagnosis, several patterns of anomalies can be detected that could lead to establishing the diagnosis (Ranu et al., 2011) .Changes in pulmonary function have been confirmed in patients previously diagnosed with COVID-19 (Torres-Castro et al., 2021). The pulmonary function test can distinguish mild, moderate, and severe post-COVID-19 syndromes (Kristyn L. Lewis et al., 2021). Patients with respiratory symptoms following COVID-19 typically exhibit anomalies in FVC (Forced Vital Capacity) and FEV (Forced Expiratory Volume), particularly those with severe symptoms (Eksombatchai et al., 2021). To be noted that while the utilisation of spirometry for a non-urgent pulmonary function assessment is generally advised against for patients diagnosed with COVID-19 during the outbreak (Klain et al., 2022), it is regarded as safe for post-COVID-19 patients (Duncan, 2023), given that they are no longer infectious after eight weeks.

The deterioration in respiratory function caused by COVID-19 infection may lead to a reduction in oxygen saturation (Anastasio et al., 2021), the ratio of oxygen-bound haemoglobin (Hafen & Sharma, 2022). This reduction in saturation can result in increased heart rate, cyanosis, fatigue, breathlessness, restlessness, and chest pain. Given the potential harm to vital organs and acute effects on various systems, including the brain, heart, and kidneys, monitoring oxygen saturation is essential for post-COVID-19 patient care. This allows for early detection of hypoxemia, a potentially life-threatening condition, guiding treatment decisions and reducing mortality rates. It also aids in optimising resource allocation, tracking disease progression, and facilitating discharge planning and public health surveillance. Therefore, routine oxygen saturation assessments are recommended for COVID-19 and post-COVID-19 patients.

Among the contributing factors that may influence pulmonary function recovery post-infection are age (Kristyn L Lewis et al., 2021), sex (Kautzky et al., 2024), obesity (Soyak Aytekin et al., 2022) and physical inactivity (Dinh-Xuan et al., 2023). Studies also suggest that post-COVID-19 symptoms can potentially be alleviated with exercises (Yang et al., 2021). While physical activity is an important determinant of physical health,(Silveira-Pérez et al., 2024) it tends to decrease during the COVID-19 pandemic (Latorre-Román et al., 2024), in contrast to

Journal of Sport and Health Research 2025, 17(2):155-167

the general recommendation to regularly engage in moderate to vigorous aerobic exercise intensity of 40-60% of the reserve heart rate or 65-75% of the maximum heart rate for at least 150 minutes per week, combined with resistance training conducted twice weekly (Jiménez-Pavón et al., 2020).

The feasibility and acute effect of combined aerobic, resistance and breathing as circuit exercise exercises in the pulmonary function and oxygen saturation among post-COVID-19 patients, has been studied among women with post-COVID-19 syndrome (Listiarini et al., 2023). All participants in the study completed the exercise safely, suggesting the feasibility of the exercise regimen (Listiarini et al., 2023). In the post-exercise assessment, significant improvements were observed in pulmonary function and oxygen saturation ($p<.001$ to 0.03), with medium to large effect sizes (0.5 to 0.8) (Listiarini et al., 2023). However, while the acute effect of exercise improves pulmonary function in post-COVID-19 women, the long-term effects warrant further exploration.

Studies focused on women are essential due to anatomical differences, such as smaller lungs, which may increase complications post-COVID-19 (Dominelli & Molgat-Seon, 2022). Women are also more prone to lingering symptoms like fatigue and are more likely to engage in health interventions (Arovah et al., 2022). This study aimed to study the exercise adaptation of the combination of circuit and breathing exercises in the pulmonary function and oxygen saturation function in post-COVID-19 women.

METHODS

Ethics consideration, study design, participants, and sample size calculation

Each participant provided informed consent, acknowledging their understanding of the research's objectives, procedures, potential risks, and anticipated benefits. This study received approval from the Semarang State University Research Ethics Commission under reference number 008/KEPK/EC/2022. The research was conducted as a randomized controlled trial involving women who were experiencing symptoms related to post-COVID-19 syndrome conducted from April to July 2022. The sample size was based on the estimated effect size of 0.8 following the findings from a preliminary study conducted in a similar population (Listiarini et al., 2023). The sample size calculation was calculated using the G*Power software and set at the significance level of 0.05, a power level of 80%, with a two-tail hypothesis assumption, and resulted in a minimum sample size of 52 participants. Anticipating a dropout rate of 15%, 60 participants were recruited. Figure 1 illustrates the participant's recruitment flow chart based on the Consort diagram.

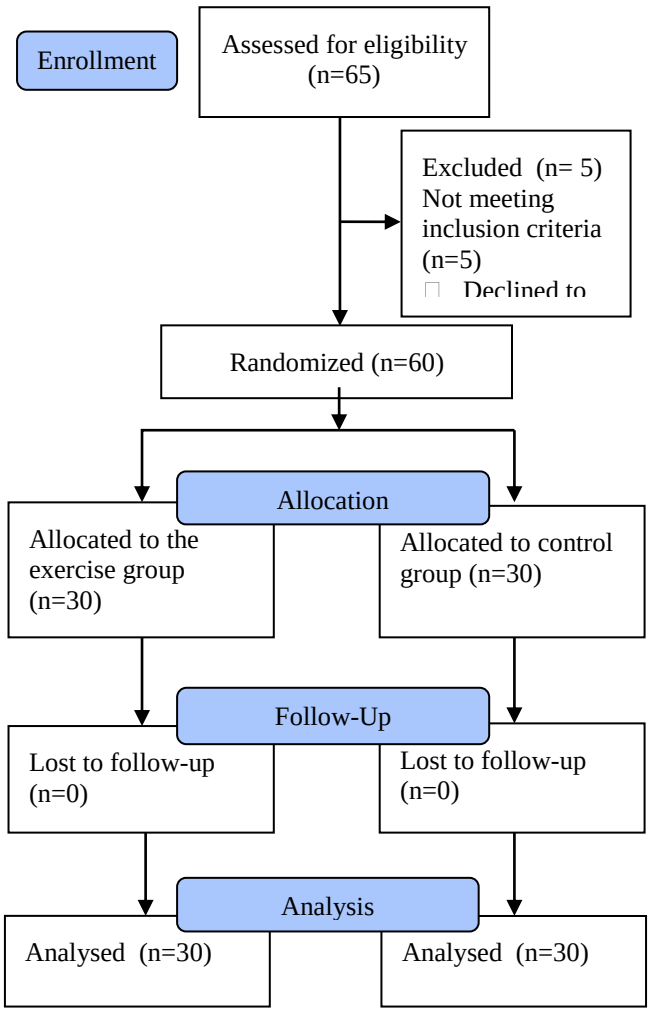

Figure 1 Participant's recruitment flow

Inclusion and exclusion criteria and recruitment allocation

To be eligible for inclusion, participants had to have been previously diagnosed with COVID-19, developed symptoms during the course of their infection, tested negative for COVID-19, and continued to experience symptoms for at least 12 weeks after their initial diagnosis. Validating

Journal of Sport and Health Research 2025, 17(2):155-167

participants' negative test results served a dual purpose: directing the study toward post-acute COVID-19 symptoms and ethically averting reinfection risk, especially in the exercise group, while also safeguarding researchers from potential COVID-19 transmission. Patients with medical conditions that prevented participation in physical activity were excluded. Those with medical conditions impeding their capacity for engaging in physical activity were excluded from participation in the study. Similarly, the discontinuation criterion was the development of medical conditions that prevented them from participating in this study.

Participants were recruited through brochures posted on social media and through the authors' network. At the commencement of the study, participants underwent randomization into either the exercise or control group, maintaining an allocation ratio of 1:1. The randomization process involved the generation of a participant list, and subsequently, the allocation sequence was determined using a mobile application employing a random number generator specifically designed for Android devices. In view of the inherent difficulties in blinding a behaviour change programme within one community, the allocation was not concealed from participants. The authors generated the allocation sequence, assigned participants to the study groups, and delivered the programme; they were not, therefore, blinded to group allocation. The research assistants involved in the data collection, as well as statisticians, were blinded to group assignments. This blinding strategy encompassed concealing group information, employing neutral identifiers for participants to research assistants, and presenting data in a de-identified format during statistical analyses.

The exercise protocol

The exercise was conducted thrice weekly for 8 weeks. The 50-minute exercise refers to a protocol published elsewhere (Listiarini et al., 2023). Figure 2 illustrates a structured exercise program divided into warm-up (A), main exercise (B), and cooling-down (C) phases. The warm-up (A), lasting approximately 10 minutes, is designed to gradually increase heart rate, monitored to reach 50-60% of maximum heart rate. It begins with marching (a) for 4 sets of 8 counts, followed by marching with shoulder rotations (b) for 2 sets of 8 counts, each forward and backwards. The routine continues with marching and dynamic triceps stretches (c) for 4 sets of 8 counts, single steps with arm swings (d) for 4 sets of 8 counts and marching with neck stretches (e) for 4 sets of 8 counts. Additional movements include shoulder stretches across the body (f) for 2 sets of 8 counts, triceps stretches (g) for 2 sets of 8 counts, and hip rotations (h) clockwise and counterclockwise for 4 sets of 8 counts.

The main exercise (B), conducted for approximately 30 minutes, follows a circuit training format with continuous movement to maintain a heart rate of 65-75% of the maximum. This section is split into aerobic cardio (B.1) and strength exercises (B.2). In Aerobic Phase 1 (B.1), participants perform four choreographic movements which included single steps with biceps curls and double steps with butterfly motions (a) for 2 sets of 8 counts, step forward/backwards with overhead presses and diagonal steps with shoulder punches (b) for 2 sets of 8 counts, V steps with low rows (c) for 2 sets of 8 counts and leg curls with lateral raises paired with grapevine steps (d) for 2 sets of 8 counts. In Aerobic Phase 2 (B.1), another 4 choreographic movements exercises included toe touches with side-outs and diagonal corner movements (e) for 2 sets of 8 counts, V steps with pumping actions and jumping jacks (f), jogging right-left and forward-backwards (g), and skipping with shoulder punches and bouncing (h), all performed continuously for 2 sets of 8 counts. The strengthening exercises (B.2) target muscle endurance, including up and down stairs (a), isometric planks (b), squats with punches (c), and lying ankle touches (d). Additional exercises include mountain climbers (e), sit-ups (f), push-ups (g), and fast feet (h) performed continuously for 30 seconds each to improve agility and strength.

The cooling-down phase (C) lasts approximately 10 minutes and focuses on flexibility and relaxation. It begins with *Namaskarasan*a (a) on an exhale, *Urdhva Hastasana* (b) on an inhale, and *Pada Hastasana* (c) on an exhale. Participants proceed with lunges like *Ekapada Prsaranasana* (d) and *Dwipada Prsaranasana* (e), followed by *Sastanga Namaskarasana* (f) and *Bhujangasana* (g). The sequence includes *Budarasana* (h) and concludes with repeated stretches—*Ekapada Prsaranasana* (i), *Pada Hastasana* (j), *Urdhva Hastasana* (k), ending with *Namaskarasana* (l), synchronized with controlled breathing for relaxation.

Journal of Sport and Health Research 2025, 17(2):155-167

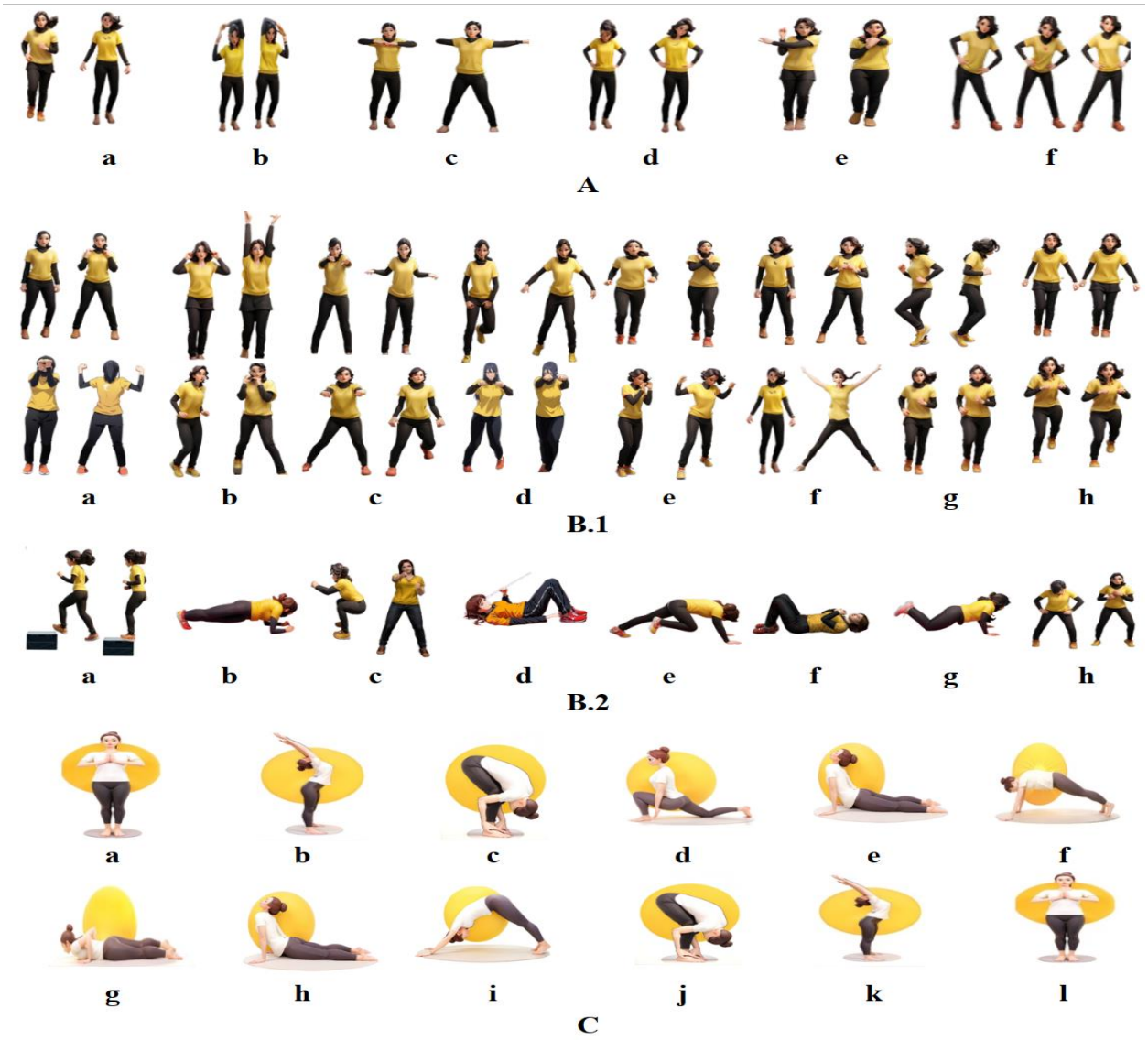

Figure 2. The Exercise Protocol

Outcome measures instruments and data collection schedule

The main outcomes of this study were pulmonary functions. The pulmonary function was assessed using the COSMED Pony FX spirometry. The assessment included [1] FVC (Force Vital Capacity), which is the maximum volume of air that can be forcefully out after inhaling as deeply as possible, [2] FEV1 (Forced Expiratory Volume 1), which is the volume of air that can be compelled to leave the lungs in a single second, [3] FEV1/FVC%, which is the percentage of lung capacity that can be exhaled in one second, [4] PEF (Peak Expiratory Flow), defined as how fast a person can exhale, [5] MVV (Maximum voluntary ventilation), which is a measure of the maximum amount of air that can be inhaled and exhaled in one minute, conducted over a 12-second time period, which is then extrapolated to the minute value [expressed in litres/minute], [6] MRf (Maximum Respiratory Frequency) which is the number of breaths per minute multiplied by tidal volume, [7] MVt (Tidal Volume during MVV) which is the volume of air that the lungs take inhale or exhale during each respiratory cycle. The oxygen saturation [SpO2] was measured using the RS232/SpO2 port embedded in the COSMED Pony spirometer unit. The SpO2 measurement was measured by placing the SpO2 port on the subject's finger while ensuring the rubber guard was intact on the pulse oximeter. During measurement, participants

Journal of Sport and Health Research 2025, 17(2):155-167

refrained from using nail polish. Participants' age, height, weight, and body mass index were assessed in the baseline. The post-COVID-19 symptoms and impact score were assessed using a validated instrument (Tran et al., 2022). These parameters were chosen because age, BMI, and symptom severity can affect lung function and recovery.

Statistical analysis

Participants' age, height, weights, body mass index, symptoms, and impact post-COVID-19 scores were summarised using descriptive statistics. A split plot RM ANOVA was used to assess the time effect (pretest and posttest), treatment effect (treatment and control), and the interaction effect between times and treatment effects on all outcome measures with pretest data assigned as covariate. These analyses were followed by calculating effect size using Cohen's d. All analyses were conducted using the IBM SPSS Statistics for Macintosh, Version 29.0. Armonk, NY: IBM Corp, with a significance level of 0.05

RESULTS

Participant's characteristics

None of the 60 participants withdrew during the duration of the study. Table 1 summarises the characteristics of participants in this study. There were no differences in anthropometric measurements and post-COVID-19 symptoms between groups.

TABLE 1. Participants' characteristics

Parameter	Control		Treatment		p
	Mean	*SD*	Mean	*SD*	
Age [years]	32.6	8.3	32.8	8.4	0.927
Height [meters]	1.5	0.06	1.5	0.06	0.553
Weight [kg]	61. 8	8.4	62.04	10.4	0.947
BMI [kg/m2]	24.7	3.03	24.5	3.9	0.804
Symptom Score	6.40	2.55	5.83	2.05	0.347
Impact Score	17.27	9.21	14.87	8.75	0.305

Note: kg- kilogram,BNI-body mass index, m2 – squared meter

Randomised control trials

The baseline or pretest measurements for oxygen saturation and pulmonary functions were similar between the treatment and control groups, except for FE1/FVC%, which exhibited a lower value in the treatment group than the control group [p=0.039]. Table 2 summarises the time, treatment, and interaction effect of the exercise on the oxygen saturation and pulmonary function results.

The effect sizes reported in Table 2 indicate the magnitude of changes observed across various pulmonary function outcomes. The effect sizes ranged from small to large, with values between -0.79 and 1.29, depending on the parameter and group. The effect sizes across outcomes reveal that the treatment intervention had a particularly notable impact on spO2, FEV1, FEV1/FVC ratio, and PEF, with moderate to large improvements in these measures. Conversely, outcomes such as MVV showed significant changes due to time but were not influenced by the treatment, while MVt exhibited minimal effects overall. The analysis of spO2 (%) revealed a significant interaction effect between time and treatment ($F(1,58) = 4.353$, $p = 0.041$), indicating that the improvement in oxygen saturation was more pronounced in the treatment group compared to the control group. However, the time effect ($F(1,58) = 2.038$, $p = 0.159$) and treatment effect ($F(1,58) = 2.848$, $p = 0.097$) were not statistically significant, suggesting that the observed differences were primarily due to the interaction of the intervention over time. This indicates that the treatment was effective in enhancing oxygen saturation levels compared to the control group.

For FVC (l), a highly significant time effect was found ($F(1,58) = 27.858$, $p < 0.001$), indicating an overall improvement in forced vital capacity from pre-test to post-test in both groups. However, the treatment effect ($F(1,58) = 1.034$, $p = 0.314$) and the interaction effect ($F(1,58) = 0.162$, $p = 0.689$) were not significant, suggesting that the improvement in FVC was consistent across both the control and treatment groups. These findings suggest that while both groups benefited from time-based factors, the treatment did not provide an additional advantage for this measure.

The FEV1 (l) results showed significant effects, particularly for time ($F(1,58) = 6.654$, $p = 0.012$) and the interaction between time and

Journal of Sport and Health Research 2025, 17(2):155-167

treatment (F(1,58) = 7.076, p = 0.010). These findings suggest that improvements in forced expiratory volume were more evident in the treatment group over time. The treatment effect itself, however, was not significant (F(1,58) = 1.879, p = 0.176), indicating that the observed changes were primarily influenced by the combined effects of the intervention and time. The results confirm that the treatment effectively enhanced FEV1 in combination with the passage of time.

For FEV1/FVC (%), a significant interaction effect was observed (F(1,58) = 8.020, p = 0.006), highlighting that the treatment group experienced a greater improvement in the ratio compared to the control group, which showed a decline. The time effect (F(1,58) = 1.703, p = 0.197) and treatment effect (F(1,58) = 0.003, p = 0.960) were not statistically significant, indicating that the main differences were due to the interaction of time and the treatment intervention. This demonstrates that the treatment was effective in maintaining or improving the FEV1/FVC ratio, which deteriorated in the control group.

The analysis of PEF (l/sec) revealed a significant time effect (F(1,58) = 7.150, p = 0.010) and interaction effect (F(1,58) = 7.284, p = 0.009), showing that peak expiratory flow improved significantly in the treatment group compared to the control group. The treatment effect (F(1,58) = 2.427, p = 0.125) was not significant, suggesting that the observed differences were driven by the interaction of time and treatment rather than treatment alone. These findings emphasize the treatment's impact in significantly enhancing PEF over time.

For MVV (l/min), there was a highly significant time effect (F(1,58) = 74.275, p < 0.001) demonstrating substantial improvements in maximum voluntary ventilation across both groups from pre-test to post-test. Neither the treatment effect (F(1,58) = 0.015, p = 0.903) nor the interaction effect (F(1,58) = 0.323, p = 0.572) were significant, indicating that the improvements were consistent regardless of the group. This suggests that factors other than the treatment intervention contributed to the improvements in MVV.

The analysis of MRf (l/min) showed a significant time effect (F(1,58) = 9.432, p = 0.003) with improvements observed in maximum respiratory frequency for both groups. However, neither the treatment effect (F(1,58) = 1.568, p = 0.215) nor the interaction effect (F(1,58) = 1.300, p = 0.259) were significant, suggesting that both groups followed a similar pattern of improvement over time. This indicates that the treatment did not provide an additional benefit for MRf beyond the improvements observed with time.

Finally, MVt (l) results indicated no significant effects across all measures. The time effect (F(1,58) = 1.511, p = 0.224), treatment effect (F(1,58) = 1.103, p = 0.298), and interaction effect (F(1,58) = 1.355, p = 0.249) were all non-significant. These findings suggest that tidal volume remained consistent from pre-test to post-test across both groups, with no notable changes due to the intervention. This implies that MVt was unaffected by the treatment or the passage of time.

In conclusion, the treatment group showed significant improvements in several pulmonary function measures, particularly spO2, FEV1, FEV1/FVC ratio, and PEF, where time × treatment interaction effects highlighted the intervention's effectiveness. While some measures, such as MVV and FVC, improved over time in both groups, the treatment-specific impact was not evident for these outcomes. Overall, the treatment intervention demonstrated its efficacy in enhancing specific pulmonary function metrics critical for respiratory health.

Journal of Sport and Health Research 2025, 17(2):155-167

TABLE 2. Time, treatment and interaction effect and effect size of the pulmonary function [n = 60]

Outcomes		Total	Control	Treatment	Effect Size	Time#	Treatment#	Time *Treatment#
spO2 (%)	Pre-test	97.9±0.8	97.9±0.8	97.9±0.8	0.11 [-0.39; 0.62]	0.159	0.097	**0.041**
	Post-test	98.1±0.7	97.9±0.7	98.4±0.5	**-0.79 [-1.31,-0.26]**			
	Effect Size	-0.18[-0.43, 0.08]	0.08 [-0.28, 0.44]	**-0.49 [-0.87, -0.11]**	-			
FVC (l)	Pre-test	3.1±0.4	3.1±0.4	3.1±0.5	-0.09 [-0.6,0.41]	**< 0.001**	0.314	0.689
	Post-test	3.5±0.3	3.4±0.3	3.5±0.2	-0.32 [-0.83,0.18]			
	Effect Size	**-0.69[-0.97,-0.40]**	**-0.66 [-1.05, -0.26]**	**-0.70 [-1.10, -0.30]**	-			
FEV1 (l)	Pre-test	2.6±0.5	2.6±0.3	2.5±0.6	0.26 [-0.24,0.76]	**0.012**	0.176	**0.010**
	Post-test	2.8±0.4	2.6±0.5	2.9±0.2	**-0.82 [-1.35,-0.29]**			
	Effect Size	**-0.32[-0.58, -0.06**]	0.01 [-0.38, 0.37]	**-0.66 [-1.05, 0.26]**	-			
FEV1/FVC (%)	Pre-test	82.5±12.9	86.0±10.8	79.1±14.1	**0.54 [0.02,1.06]**	**0.197**	0.960	**0.006**
	Post-test	79.4±11.8	76.1±15.7	82.7±3.3	**-0.58 [-1.10,-0.06]**			
	Effect Size	-0.16[-0.10,0.41]	**0.47 [0.09, 0.84]**	-0.23 [-0.59, 0.13]	-			
PEF (l/sec)	Pre-test	4.1±1.3	4.2±1.1	3.9±1.5	0.21 [-0.29, 0.71]	**0.010**	0.125	**0.009**
	Post-test	4.7±1.4	4.2±1.4	5.2±1.0	**-0.80[-1.33, -0.27]**			
	Effect Size	**-0.33[-0.59,-0.67]**	0.00 [-0.35, 0.36]	**-0.67 [-1.07, -0.27**]	-			
MVV (l/min)	Pre-test	53.3±11.1	53.7±9.5	52.7±12.5	0.08 [-0.42, 0.59]	**<0.001**	0.903	0.572
	Post-test	71.5±11.1	70.8±12.7	72.2±9.2	-0.13 [-.63, 0.37]			
	Effect Size	**-1,12[-1,44,-0.79]**	**-0.97 [-1.40,-0.53]**	**-1.29 [-1.77, -0.79]**	-			
MRf (l/min)	Pre-test	81.5±24.5	81.2±21.7	81.7±27.5	-0.02 [-0.53, 0.48]	**0.003**	0.215	0.259
	Post-test	93.4±18.3	88.6±22.7	98.1±10.8	**-0.53 [-1.04, -.01]**			
	Effect Size	**-0.40[-0.66,-0.13]**	-0.24 [-.60, 0.12]	**-0.56 [-0.94, -0.17]**	-			
MVt (l)	Pre-test	0.7±0.4	0.7±0.3	0.7±0.3	-0.01 [-0.51, 0.49]	0.224	0.298	0.249
	Post-test	0.8±0.3	0.9±0.3	0.7±0.1	0.47 [-.04, 0.98]			
	Effect Size	-0.16[-0.41,-0.10]	-0.29 [-0.65, 0.08]	-0.01 [-0.37, 0.35]	-			

Note: FVC - Forced Vital Capacity, FEV1 - Forced Expiratory Volume 1, PEF - Peak Expiratory Flow, MVV - Maximum voluntary ventilation, MRf - Maximum Respiratory Frequency, MVt - Tidal Volume [during MVV], spO2- oxygen saturation, p=p value, ES = effect size, Bold: Significant

Journal of Sport and Health Research 2025, 17(2):155-167

DISCUSSION

The positive impact of exercise on pulmonary function has been well-established in healthy populations, as demonstrated by numerous studies (Angane & Navare, 2016). However, there is a notable gap in research regarding the effect of exercise on pulmonary function and oxygen saturation in COVID-19 and post-COVID-19 patients. While a study has investigated the acute effects of circuit involving aerobic, strength and breathing exercises on pulmonary function and oxygen saturation among post-COVID-19 patients (Listiarini et al., 2023), this study is the first study aiming to investigate the longer-term effect of the exercise programs on these parameters.

The results of this study revealed significant improvements in oxygen saturation and key pulmonary metrics, including FEV1, FEV1/FVC, PEF, and MRf among participants who engaged in the 8-week exercise program, when compared to those in the control group. Interestingly, both groups exhibited comparable improvements in FVC and MVV. Furthermore, a noteworthy decline in FEV1/FVC% was observed in the control group, while MVt remained unchanged in both groups. These findings underscore the clear advantages of the eight-week exercise program, which combines aerobic, strength and breathing exercises.

These outcomes align with several other studies in the field. One study highlighted improved functional capacity through breathing exercises, specifically incentive spirometry and diaphragmatic exercises (Amien et al., 2022). Similarly, the improvement of pulmonary function has also been reported after a single session of the combination of aerobic, strength, and breathing exercises in post-COVID-19 women (Listiarini et al., 2023). Nevertheless, it's worth noting a prospective observational study which found no significant disparities in respiratory function between COVID-19 patients who received respiratory exercises and those who did not (Aydýn et al., 2022).

The conflicting results in studies exploring the impact of exercise on pulmonary function among COVID-19 and post-COVID-19 patients can be attributed to several factors. COVID-19 affects individuals differently, with varying degrees of severity and complications. Studies may include patients with diverse clinical profiles, which can lead to varied responses to exercise interventions. Additionally, differences in intervention protocols, such as types, durations, and intensities of exercise programs, can yield different outcomes. The timing of exercise interventions concerning the course of the disease, variations in measurement techniques, and small sample sizes can all contribute to the conflicting findings. In addition, the relatively stable Tidal Volume (MVt) in both groups raises intriguing questions about the specific mechanisms by which the exercise program influenced respiratory parameters. Future studies may delve deeper into these aspects to elucidate the underlying physiological processes. This underscores the complexity of studying post-COVID-19 recovery, emphasising the need for precise study design and data interpretation. This underscores the need for further research and careful consideration of the implications for respiratory rehabilitation in this context.

This study also demonstrated that the 8-week circuit training improved oxygen saturation. The training potentially enhance cardiovascular fitness (Amaro-Gahete et al., 2019), leading to more efficient oxygen transport, while the breathing exercises optimise respiratory muscle function and lung capacity (Lu et al., 2020) further boosting oxygen levels. The increased oxygen saturation may be attributed to the improved pulmonary function metrics like FEV1, FEV1/FVC, PEF, and MRf, which signified improved breathing efficiency. This feedback loop potentially supports better oxygenation and exercise performance. However, the improvement in FVC and MVV in the control group in this current study is also notable, with possible reasons including natural recovery of the disease. However, FEV1/FVC% worsened in the posttest compared to the pretest in the control group, thus supporting the benefit of the exercise program in elevating pulmonary function and oxygen saturation compared to those who did not partake in the program. Overall, the findings of this study suggest that the circuit training may play a crucial role in post-COVID-19 rehabilitation by optimising oxygen saturation and pulmonary function.

This study has established that circuit training, 50 minutes thrice weekly at moderate intensity, improve oxygen saturation and pulmonary functions, using a randomised controlled trial design with a standardised intervention protocol. However,

Journal of Sport and Health Research 2025, 17(2):155-167

several potential limitations of this study need to be acknowledged. Firstly, while the study was intentionally designed to focus on women with post-COVID-19 symptoms due to known gender differences in pulmonary function, future research should include male participants to enhance the generalizability of these findings.. Second, the 8-week duration of the intervention may not capture the long-term effects or sustainability of the observed improvements. Longitudinal studies with extended follow-up periods can assess the durability of improvements. Third, while the severity levels of the control and treatment groups were similar, this study may not capture participants with varying severity levels of COVID-19, potentially impacting their response to exercise. In this regard, multi-centre trials would account for variations in patient populations and treatment protocols and personalised exercise programs tailored to individual characteristics could be explored. Mechanistic studies could delve into the underlying physiological processes, while patient-reported outcomes could provide valuable subjective insights. Lastly, investigating the synergistic effects of exercise in combination with other rehabilitation modalities or medical treatments could enhance overall post-COVID-19 recovery strategies. Future research can refine our understanding and approach to post-COVID-19 rehabilitation by addressing these considerations.

CONCLUSIONS

In conclusion, this randomised controlled trial demonstrates that the circuit combining aerobic, strength and breathing exercise within the 8-week exercise program effectively enhances pulmonary function in women with post-COVID-19 syndromes. The treatment group exhibited significant improvements in oxygen saturation and pulmonary functions compared to the control group after the exercise program. While the control group also showed some improvements in pulmonary functions by the end of week 8, these were of smaller magnitude. This underscores the importance of specific treatments like the exercise program in achieving substantial gains in pulmonary function. Enrolling women with post-COVID-19 in such programs, thus, is advised for improved pulmonary function. Future research should consider longitudinal studies, comparative trials, and multi-centre approaches for a comprehensive understanding.

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