Effects of inspiratory muscle training on lung function, muscle oxygenation and functional capacity in older adults

Efectos del entrenamiento muscular inspiratorio en la función pulmonar, oxigenación muscular y capacidad funcional en adultos mayores

Autores

Rodrigo Yáñez-Sepúlveda[1]
Matías Monsalves-Álvarez[1]
Marcelo Tuesta[1]
Aldo Vásquez-Bonilla[2]
Gladys Orellana-Lepe[3]
Lilian Castro-Tapia[3]
Pamela Ruiz[4]
Jacqueline Páez-Herrera[5]
Jorge Olivares-Arancibia[6]
María Martínez-Olcina[7]
Ildefonso Alvear-Ordenes[8]
Alejandro Martínez-Rodríguez[7]

[1]Universidad Andres Bello (Chile)
[2]Universidad de Extremadura (España)
[3]Universidad Viña del Mar (Chile)
[4]Universidad de Playa Ancha (Chile)
[5]Pontificia Universidad Católica de Valparaíso (Chile)
[6]Universidad de las Américas (Chile)
[7]Universidad de Alicante (España)
[8]Universidad de León (España)

Autor de correspondencia:
Rodrigo Yáñez-Sepúlveda
rodrigo.yanez.s@unab.cl

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Abstract

Background and objective. Inspiratory muscle training (IMT) generates positive effects on physical performance, but there is little evidence on the effects on muscle resaturation in older adults. The study aimed to assess the impact of a 4-week Inspiratory Muscle Training (IMT) program on peak dynamic inspiratory strength, lung function, muscle oxygenation and functional capacity in functionally independent older adults.
Material and methods. Twelve randomized older adults (EG= n6; 68.8 ± 2.6 years; SCG=n6, 71.5 ± 4.7years) completed the study. A 4-week IMT program was applied, along with general physical activity recommendations. Activities of daily living, lung flow and volumes, peak dynamic inspiratory force (S-index), peak inspiratory flow (MIF), muscle resaturation velocity (ΔTSIreoxy) by NIRS and the Senior Fitness Test battery were assessed pre and post intervention.
Results. Improvements in the EG in the Chair Stand Test ($p=0.013$; $\eta^2_p=0.474$), Biceps Curl Test ($p=0.015$; $\eta^2_p=0.463$) and 6 minutes walking test ($p=0.011$; $\eta^2_p=0.495$), while in the control group changes were observed only in Biceps Curl Test ($p=0.004$; $\eta^2_p=0.589$). An increase in EG was observed in the S-Index ($p=0.038$; $\eta^2_p=0.363$) with a high effect on peak inspiratory flow (MIF) ($p=0.138$; $\eta^2_p=0.206$), finally EG showed a high effect size on muscle resaturation velocity at the end of exercise ($p=0.213$; $\eta^2_p=0.187$; Δ=-31%).
Conclusions. Short IMT program increases S-index, physical capacity and muscle oxygenation velocity. IMT may be a complementary intervention strategy in older adults to improve their physical fitness and peripheral vascular response.

Keywords

Exercise; NIRS; older adults; respiratory therapy.

Resumen

Antecedentes y objetivo. El entrenamiento muscular inspiratorio (EMI) genera efectos positivos en el rendimiento físico, pero existen pocas pruebas sobre los efectos en la resaturación muscular en adultos mayores. El objetivo del estudio fue evaluar el impacto de un programa de entrenamiento muscular inspiratorio (EMI) de 4 semanas sobre la fuerza inspiratoria dinámica máxima, la función pulmonar, la oxigenación muscular y la capacidad funcional en adultos mayores funcionalmente independientes.
Material y métodos. Doce adultos mayores aleatorizados (EG= n6; 68,8 ± 2,6 años; SCG=n6, 71,5 ± 4,7años) completaron el estudio. Se aplicó un programa de EMI de 4 semanas, junto con recomendaciones generales de actividad física. Se evaluaron las actividades de la vida diaria, el flujo y los volúmenes pulmonares, la fuerza inspiratoria dinámica máxima (índice S), el flujo inspiratorio máximo (FIM), la velocidad de resaturación muscular (ΔTSIreoxy) mediante NIRS y la batería Senior Fitness Test antes y después de la intervención.
Resultados. Mejoras en el GE en la prueba de pararse y sentarse de la silla ($p=0,013$; $\eta^2p=0,474$), test de curl de bíceps ($p=0,015$; $\eta^2p=0,463$) y test de caminata de 6 minutos ($p=0,011$; $\eta^2p=0,495$), mientras que en el grupo control sólo se observaron cambios en el test de curl de bíceps ($p=0,004$; $\eta^2p=0,589$). Se observó un aumento del GE en el índice S ($p=0,038$; $\eta^2p=0,363$) con un elevado efecto sobre el flujo inspiratorio máximo (FIM) ($p=0,138$; $\eta^2p=0,206$), finalmente el GE mostró un elevado tamaño del efecto sobre la velocidad de resaturación muscular al final del ejercicio ($p=0,213$; $\eta^2p=0,187$; Δ=-31%).
Conclusiones. Un programa corto de EMI aumenta el índice S, la capacidad física y la velocidad de oxigenación muscular. El EMI puede ser una estrategia de intervención complementaria en adultos mayores para mejorar su forma física y su respuesta vascular periférica.

Palabras clave

Adultos mayores; ejercicio; NIRS; terapia respiratoria.

Introduction

Several studies have been conducted with IMT in older adults in recent years. Still, no studies have been undertaken to identify the effects of IMT on muscle oxygenation, so this study provides relevant information on this methodology in fractional O2 extraction (Mello et al., 2024). Several studies show that the aging process generates a decrease in quality of life, overall functional quality, and mitochondrial dysfunction (Guralnik et al., 2021). It has been seen that as we age the prevalence of chronic non-communicable diseases such as hypertension (Shalaeva & Messerli, 2023), asthma (Nanda et al., 2020) and peripheral vascular disease increases which brings problems in health and quality of life (Ostchega et al., 2007), where, particularly in the case of obstructive disease, the inspiratory muscles work under unfavorable mechanical conditions, generating dyspnea and fatigue (Cortopassi et al., 2017).The aging of the population increases the prevalence of respiratory diseases, generating a public health problem. These conditions increase morbidity and mortality, increasing health expenditure, and respiratory tract diseases are currently the third leading cause of mortality in older adults (Joshi, 2024). The atrophy and weakness of muscle fibres that occurs with age in the respiratory muscles along with the systemic skeletal muscle is known as respiratory sarcopenia, in older adult respiratory sarcopenia can lead to respiratory problems and negative health effects (Nangano et al., 2021).

Physical exercise has been found to be a reliable tool to improve quality of life in the older adult, generating improvements in muscle strength (Labott et al., 2020), cognition (Bherer et al., 2021), cardiorespiratory fitness (Hurst et al., 2019), prevalence of cardiovascular disease (Lachman et al., 2018) and other clinical conditions such as cancer (Mikkelsen et al., 2020). Within intervention strategies, respiratory muscle training (IMT) programs have recently been applied that have generated an increase in inspiratory muscle hypertrophy and strength (Manifield et al., 2021; Seixas, et al., 2020), improved measures of spirometry, exercise tolerance and respiratory muscle strength (Mills et al., 2015). But there is scant evidence of the effects of IMT on muscle oxygenation analyzed with near-field infrared spectroscopy (NIRS) in older adults. In recent years, NIRS has become a tool to monitor exercise-induced adaptations and aging in this population (Chung et l., 2018). This tool has positioned itself as an easy-to-apply strategy that allows monitoring the effects of exercise interventions in both clinical (Hamaoka et al., 2011) and sport settings (Perrey & Ferrari, 2018). Thus, identifying the effects of IMT on muscle oxygenation becomes of interest and opens an area of research in exercise for health. Because of this, the aim of the study was to assess the impact of a 4-week Inspiratory Muscle Training (IMT) program on peak dynamic inspiratory strength, lung function, muscle recovery and functional capacity in functionally independent older adults.

Method

Study Design and randomization

The study consisted of a 4-week experimental, randomized, parallel-design clinical trial. An experimental study was developed with two random groups: an experimental group (EG) and sham control group (SCG). Randomization was performed by a professional who did not participate in the intervention or in the project evaluations. Once the study population was identified, random sampling was performed to divide the sample into the groups indicated above. In this study, randomization was performed with the randomization program https://www.randomizer.org/.

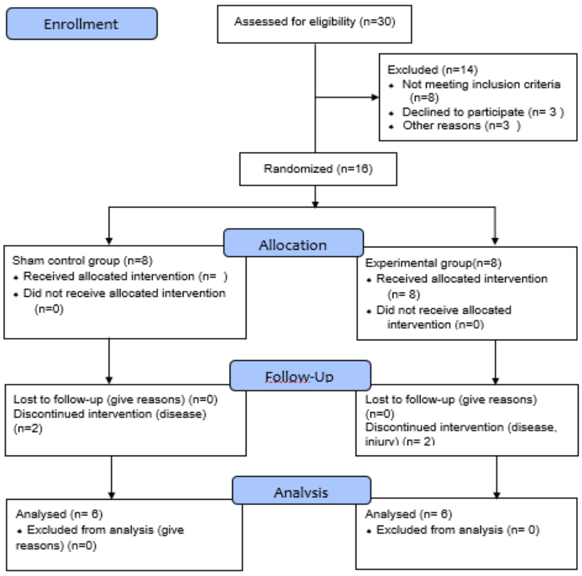
Sample calculation

The sample was calculated before the intervention using the mean and standard deviation of S-index values obtained before and after an intervention with inspiratory muscle training in older adults (S-index: PRE: 80±7 cmH2O; POST: 124±6; variation 44 cmH2O) (Rodrigues et al., 2020). The initial universe of was 30 participants who met the eligibility criteria. For the sample calculation, a bilateral contrast was applied with the statistical software G*Power® 3.1.9.7, Düsseldorf, Germany, an alpha risk of 5% with a beta risk of 20% (statistical power of 80%), a loss-to-follow-up ratio of 20% and an inter-group ratio of 1 to 1 were considered. From this analysis, a minimum of 6 subjects per study group was estimated.

Participants

From a total of 30 older adults who met the inclusion criteria, 16 were randomly assigned (EG=n8; SCG=n8), with 12 participants finally completing the study (EG=n6; SCG=n6) (figure 1). Prior to the evaluations, a familiarization session on the use of the respiratory training device was performed. The Inclusion criteria were older adults with functional independence (>80 points on the Barthel index), without obstructive respiratory diseases and who will not use medications that alter autonomic function. Exclusion criteria were participants who did not perform more than 90% of the scheduled IMT sessions, had obstructive or restrictive respiratory disorders or clinical conditions that prevented completion of the study protocol. For various reasons, 2 subjects dropped out of the study in GE and 2 in SCG (Figure 1).

Figure 1. Consort 2010 flow diagram.



Recruitment

Recruitment was done through the Universidad del Adulto Mayor (UDAM) of the Universidad Viña del Mar. Older adults were contacted through posters and talks, e-mails and others.

Ethical considerations

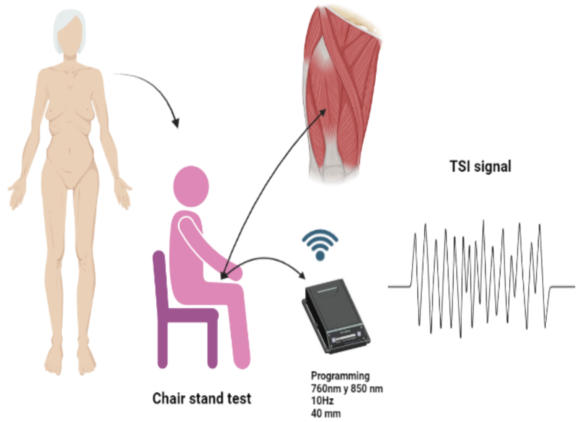
First, a session was held to explain the objectives and scope of the study. Then, the participants signed an informed consent form containing the objectives and procedures to be developed during the study. The protocol and development of the present study was approved by the Scientific Ethics Committee (SEC) of the Universidad Viña del Mar (Code R62-19a). This research was conducted following the recommendations of the Helsinki declaration (World Medical Association, 2013).

Procedures

Assessments

The assessments were conducted at the Universidad Viña del Mar facilities. The assessment protocol was performed by a previously trained professional team and all study participants were familiarized with the assessments prior to their application. The measurements were performed at an ambient temperature between 18º and 22º Celsius. The protocols used for the present study are detailed below (Figure 2).

Figure 2. Evaluation test



Anthropometry

Prior to the physical condition assessments and after urinary voiding, the evaluations were performed. For the evaluation of body mass (kg) and height (m) a mechanical scale with measuring rod (Model M2081; SECA®, Hamburg, Germany) was used, the medial thigh fold (mm) was evaluated with a Harpenden® adipometer (Baty Int., UK). All assessments were performed based on the recommendations of the International Society for the Advancement of Cineanthropometry (ISAK). The evaluations were performed in underwear and barefoot; the following criteria were considered for the evaluation: 1. Fasting for a minimum of 4 hours. 2. No caffeine consumption. 3. Not having consumed alcohol 24 hours before the evaluations. 4. 5. Not having exercised 24 hours before the evaluations. 6. Not being dehydrated (Carrion et al, 2019).

Level of functional Independence

Before the physical capacity evaluations, functional dependence was assessed with the Barthel Index for the following activities of daily living: transfers, walking, climbing stairs, toileting, dressing, feeding, bladder control, bowel control, grooming and bathing. This index measures the patient's performance and independence in self-care, sphincter management, transfers and locomotion. The score ranges from 0 to 100, scores below 20 points are interpreted as total dependence and above 80 as functional independence (Mahoney & Barthel, 1965). It is a validated measure of activities of daily living (ADLs) that is recommended for use in research among the elderly (Hopman-Rock et al., 2019). All assessments were conducted by the same practitioner.

Functional capacity

The Senior Fitness Test battery was applied considering the following six functional tests.

1. The chair stand test. This requires individuals to repeatedly stand and sit in a chair for 30 seconds. The number of stands is recorded. This reflects lower body strength.
2. The biceps curl test. This requires individuals to repeatedly lift a weight of 2.27 kg (5 pounds) (for women) or a weight of 3.63 kg (8 pounds) (for men) for 30 seconds. The number of elevators is recorded. This reflects upper body strength.
3. The 6-minute walk test (6MWT). This is measured in distance (m) and reflects aerobic endurance. The original version of the Senior Fitness Test required people to walk a rectangular course, but newer versions use a straight line. If a 6MWT is not feasible, then it is acceptable to replace this test with the 2-minute step test. The number of complete steps completed in 2 minutes is recorded.
4. The sit and reach test. This is measured in distance (cm) and reflects lower body flexibility.
5. The back scratch test. This is measured in distance (cm) and reflects the flexibility of the upper body.

6. The 2.45 m Up-and-Go test. This is measured in time (seconds) and reflects agility and dynamic balance (Langhammer, B. & Stanghelle, 2015).

Handgrip

A JAMAR® brand digital device (Patterson Medical, Bolingbrook, IL, USA), Plus model with an accuracy of 0.1kg, was used for the evaluation. Prior to familiarization, 3 measurements were taken for each hand in intercalated order (dominant hand then non-dominant hand) and the highest value obtained was considered; no stimulus of any kind was provided during the evaluation (Mehmet et al., 2020). During the assessment the participant was seated in a chair without armrests, with the hip flexed at 90° and the feet resting on the floor. The elbow of the test arm was flexed to 90°, the forearm in neutral position and the wrist was positioned at 15-30° of extension (dorsiflexion) and 0-15° of ulnar deviation. The examiner supported the dynamometer base for the test and the second smallest position of the dynamometer handle was used (Wearing et al., 2018), a rest of at least 30 seconds was considered between assessments and the result was recorded in kilograms.

Muscle restauration by NIRS

The subjects were placed in a seated position in a chair with ergonomic backrest, then the measurement area was shaved and cleaned with isopropyl alcohol at 70º, then the skin fold was measured and recorded with a Harpenden® adipometer (Great Britain), the evaluation was performed in the muscle belly of the vastus lateralis of the quadriceps muscle approximately 15 cm above the upper edge of the patella and 5 cm laterally parallel to the muscle fibers. An Artinis Medical Sistem brand continuous wave (CW) NIRS device, model Portamon® (The Netherlands), was installed in the area, the NIRS was programmed at a wavelength of 760nm and 850 nm and a sampling frequency of 10Hz (Jones et al., 2018; Paradis-Deschênes et al., 2020). The evaluation started 5 minutes after the installation of the equipment. The measurement site was marked with a dermographic pencil and the NIRS device was fixed with dermal adhesive tape, during the evaluation the extremity was covered with a black cloth to avoid ambient light interference on the analyzed signal. For data analysis, the third NIRS recording channel (40mm) was used because it allows a higher level of tissue penetration (Graham et al., 2019). After the evaluation, the data were reviewed and analyzed in Oxysoft software and then passed to an Excel spreadsheet on computer for further statistical analysis. The baseline tissue saturation index (TSIbas) was calculated as the average of the minute prior to exercise once the NIRS signal had stabilized, this was assessed on a clinical couch in the supine position. The minimum saturation value (TSImin) was calculated based on the lowest value reached during the sit-to-stand test in 30s and the maximum saturation value (TSImax) was calculated during the performance of the test, the reoxygenation rate from minimum to basal (ΔTSIreoxy) was calculated based on the resaturation time in seconds from the minimum value to reach basal immediately after the exercise was completed. The difference between TSImin-TSImax (Δ TSI min-max) during the application of the sit-to-stand test in 30s was also evaluated.

Pulmonary function

A portable spirometer from the manufacturer Viasys Healthcare model Microlab® (USA) was used, previously calibrated with a 3L syringe. Based on the recommendations and suggestions of the American Thoracic Society (ATS) and the European Respiratory Society (ERS) (Graham et al., 2019; Miller & Enright, 2012), the pulmonary function variables Forced Expiratory Volume in 1 Second (FEV1 (l)), Forced vital capacity (FVC (l)), Pulmonary Function Testing (PEF (l/m)), FEV1/FVC (%), Forced mid-expiratory flow between 25% and 75% (FEF 25%-75% (l/s)) and Maximal voluntary ventilation (MVV (l/min)) were obtained, MVV was obtained by multiplying FEV1 x 37.5. The evaluation was performed in a seated position on a chair fixed to the floor, before the evaluation a nasal clip was installed on each individual, which he/she had to keep on while inspiration and expiration were performed up to maximum capacity. For the analysis of the results, the best values obtained considering compliance with the ATS/ERS criteria were used. The data were transferred manually to an Excel spreadsheet after checking the quality criteria.

Maximal dynamic inspiratory force

The maximum dynamic muscle strength (S-Index) and the maximum inspiratory flow (MIF) were evaluated with a device from the manufacturer HaB International Ltd, model POWERbreathe Kinetic K5® (United Kingdom). After a familiarization process on the use of the device and to avoid the learning effect, a warm-up of the respiratory muscles was performed (Volianitis et al., 2001). Then, starting from the residual volume, each subject, seated on a chair fixed to the floor and with a nose clip, performed a maximum of 10 maximal inspiratory efforts, from these efforts the values of the 3 best efforts without differences greater than 10% between them were chosen for the analysis of the results. In this study, a rest interval of 1 to 1.5 minutes between consecutive efforts was considered during the evaluation.

Intervention

The intervention was carried out by a Physical Education teacher with a specialization in exercise prescription for health. To maintain adherence, weekly messages were sent via mobile phone to motivate participants. During the study the participants carried out their normal activities and did not participate in any other physical exercise program. An inspiratory muscle training program was carried out for 4 weeks. Both groups were given daily physical activity (PA) recommendations in order to keep them physically active; physical activity was recorded with self-reporting in a personal notebook. Before the start, the equipment was adjusted to the initial value of each subject (50% S-Index in EG and 5% S-Index in SCG) and 3 familiarization sessions were carried out on the use and care of the device; in this study, the POWERbreathe® beginner level (green) model device from the manufacturer HaB International Ltd (United Kingdom) was used. The intervention was performed 5 days a week (one session in the morning and one in the afternoon), leaving weekends free. In each session, participants performed 30 dynamic inspirations based on the programmed load at 50% of the initial S-Index, while the SCG used a simulated load during the intervention (5%S-Index). In addition, possible adverse events caused by the training plan were recorded, such as dyspnea, nausea, headache and others. In the present study, none of the participants reported adverse effects at the time of the training sessions.

Statistical analysis

The normality of the data was determined with the Shapiro Wilk test. Homogeneity of variances was analyzed with Levene's test. Mean and standard deviation statistics were used to represent the study variables, percentage changes expressed as percent change pre and post (Δ) were also considered. To compare pre and post IMT results (two times), an analysis of variance (ANOVA) considering an intrasubject factor, Bonferroni's post hoc test was used. A partial eta squared test ($\eta^2 p$) was also performed considering values of <0.01, >0.059 and >0.138, classifying as small, medium and large effect sizes, respectively (Richardson, 2011). Finally, the effect size of the intervention was calculated through Cohen's d test, being classified as follows: no effect (<0.2), small (>0.2 to 0.5), medium (>0.5 to 0.8) and large (≥ 0.8) (Cohen, 1988). JAMOVI® version 1.6 software (Sydney, Australia) was used for statistical analysis. For all statistical tests, a p-value <0.05 was considered significant.

Results

Out of a total of 16 participants only 12 completed the study, a loss of 25% of the cases. The sample that finally completed the study in the EG was 6 subjects in the EG (68.8 ± 2.6 years) and 6 subjects in the SCG (71.5 ± 4.7 years). Table 1 shows the basic variables of the participants. No differences were found between the groups.

Table 1. Baseline characteristics of the study groups

Variable	SGC (n=6)					EG (n=6)					Within-subject effects EG			Within-subject effects SCG		
	PRE		POST		Δ	PRE		POST		Δ	F	p	η^2_p	F	p	η^2_p
Weight (kg)	73.92	7.59	74.23	7.85	0%	72.72	9.26	72.38	9.27	0%	0.003	0.952	0.000	0.000	0.945	0.001
Height (m)	1.59	0.07	1.59	0.08	0%	1.58	0.03	1.57	0.03	-1%	0.220	0.649	0.021	0.000	0.969	0.000
BMI (kg/m²)	29.33	2.94	29.33	3.27	0%	29.17	3.66	29.33	3.72	1%	0.006	0.940	0.001	0.010	0.907	0.001
ATT (mm)	20.17	7.49	19.67	7.66	-2%	19.67	8.16	19.17	8.04	-3%	0.011	0.917	0.001	0.013	0.911	0.001

ATT: adipose tissue thickness. EG: experimental group; SCG: sham control group. *Significant differences between active and, with p-value < 0.05.

Table 2 shows the results obtained in the variables of activities of daily living and physical condition. Changes in the EG were observed in the Chair Stand Test ($p=0.013$; $\eta^2 p=0.474$), Biceps Curl Test ($p=0.015$; $\eta^2 p=0.463$) and 6 minutes walking test ($p=0.011$; $\eta^2 p=0.495$), while in the control group changes were observed only in Biceps Curl Test ($p=0.004$; $\eta^2 p=0.589$).

Table 2. Pre- and post-intervention comparative analysis of activities of daily living and physical fitness

Variable	SCG (n=6)					EG (n=6)					Within-subject effects EG			Within-subject effects SCG		
	PRE		POST		Δ	PRE		POST		Δ	F	p	η^2_p	F	p	η^2_p
Barthel Index (BI)	98.33	2.58	97.50	2.74	-1%	97.50	2.74	95.00	4.47	-3%	1.360	0.270	0.120	2.500	0.145	0.200
Chair stand test	12.83	2.32	13.00	0.63	1%	15.83	1.94	22.17	4.79	40%	9.000	0.013	0.474	0.028	0.868	0.003
2.45-m Up-and-Go test	7.08	0.85	7.72	1.52	9%	6.23	1.11	5.73	1.00	-8%	0.668	0.433	0.063	0.821	0.386	0.076
Curl Bíceps Test	12.67	1.97	17.50	2.43	38%	15.17	2.04	21.33	4.72	41%	8.630	0.015	0.463	14.400	0.004	0.589
Chair Sit and Reach Test	-11.80	1.28	-2.00	5.44	83%	-4.32	16.69	1.83	15.64	142%	0.434	0.525	0.042	3.200	0.104	0.242
Back Scratch Test	-7.58	13.84	-13.00	10.39	-71%	-5.27	10.00	2.35	9.78	145%	1.780	0.212	0.151	0.588	0.461	0.056
6 minutes walking test	335.2	45.9	315.2	36.2	-6%	350.7	97.8	495.3	56.8	41%	9.81	0.011	0.495	0.702	0.422	0.066
Handgrip Right	20.42	5.41	23.70	4.19	16%	23.73	4.57	26.07	4.37	10%	0.816	0.388	0.075	1.38	0.267	0.121
Handgrip Left	19.83	5.70	23.77	4.86	20%	21.72	5.07	25.18	5.34	16%	1.330	0.276	0.277	1.65	0.228	0.142

EG: experimental group; SCG: Sham control group. Δ: variation post/pre intervention. *Significant differences between active and with p-value < 0.05

Table 3 shows the results obtained in the variables of inspiratory dynamic force and lung volumes. An increase in EG was observed in the S-Index ($p=0.038$; $\eta^2_p=0.363$) with a high effect on peak inspiratory flow (MIF) ($p=0.138$; $\eta^2_p=0.206$). In SCG, no differences or high effects were observed in the variables analyzed.

Table 3. Comparative analysis pre and post intervention in the variables of inspiratory dynamic force and lung volumes

Variable	SCG (n=6)					EG (n=6)					Within-subject effects EG			Within-subject effects SCG		
	PRE		POST		Δ	PRE		POST		Δ	F	p	η^2_p	F	p	η^2_p
S-index (cmH_2O)	47.17	17.99	44.00	15.88	-7%	58.67	18.71	84.33	18.52	44%	5.700	0.038	0.363	0.105	0.753	0.010
MIF ($L\text{-}min^{-1}$)	2.68	1.12	2.37	0.78	-12%	3.37	1.15	4.48	1.24	33%	2.600	0.138	0.206	0.301	0.585	0.031
FEV_1	2.02	0.52	2.01	0.51	0%	2.14	0.27	2.23	0.36	4%	0.245	0.632	0.024	5.05	0.983	0.000
FVC	2.49	0.71	2.40	0.43	-4%	2.80	0.39	2.91	0.52	4%	0.157	0.700	0.015	0.07	0.796	0.007
PEF	273.50	96.61	272.50	77.30	0%	345.67	114.91	392.33	68.16	14%	0.732	0.412	0.068	2.920	0.985	0.000
FEV_1/FVC_1	81.67	6.56	76.67	5.24	-6%	79.83	8.75	77.17	5.34	-3%	0.026	0.873	0.003	0.169	0.690	0.017
$FEF_{25\text{-}75\%}$	2.19	0.64	2.15	0.68	-2%	1.77	0.54	1.83	0.47	3%	0.037	0.851	0.004	0.011	0.918	0.001
MVV	75.72	19.62	75.37	19.03	0%	80.27	10.01	83.57	13.58	4%	0.230	0.642	0.022	9.830	0.976	0.000

EG: experimental group; Vo2max: maximum oxygen uptake; FEV_1: Forced expiratory volume in first 1 second; FVC: Forced vital capacity; FEV_1/FVC_1 $FEF_{25\text{-}75\%}$: Forced expiratory flow between 25% and 75% of the maximal flow; MVV: maximal voluntary ventilation: PEF: Peak expiratory flow; SCG: Sham control group. Δ variation post/pre intervention. *Significant differences between active and with p-value < 0.05

Table 4 shows the results obtained in the muscle oxygenation variables. In EG, a high effect size was observed in the reoxygenation speed at the end of exercise ($p=0.213$; $\eta^2_p=0.187$; Δ=-31%). In the other variables, no changes or high effects were seen in the groups.

Table 4. Comparative analysis pre and post intervention in the variables fractional extraction.

Variables	SCG (n=6)					EG(n=6)					Within-subject effects EG			Within-subject effects SCG		
	Baseline		POST			Baseline		POST								
	Mean	DS	Mean	DS	Δ	Mean	DS	Mean	DS	Δ	F	p	η^2_p	F	p	η^2_p
TSI baseline (%)	67.9	9.2	67.8	7.99	0%	70.4	4.78	69.3	3.33	-2%	0.189	0.676	0.023	3.100	0.986	0.000
TSI minimun (%)	55.2	15.5	57.7	14.6	5%	57.2	3.42	56.5	5.84	-1%	0.054	0.822	0.007	0.070	0.797	0.009
Δ TSIreoxy (s)	36.5	15.5	36.9	16.4	1%	43.7	15.3	30.2	16.3	-31%	1.83	0.213	0.187	0.001	0.972	0.000
TSImas (%)	74.1	8.52	74.3	9.07	0%	72	4.53	74.8	5.66	4%	0.754	0.411	0.086	6.880	0.980	0.000
Δ TSI min-max	18.9	8.86	16.5	7.81	-13%	14.9	4.42	18.3	10.9	23%	0.420	0.535	0.050	0.203	0.665	0.025

EG: experimental group; HHb: deoxyhemoglobin; SCG: Sham control group; TSI: Tissue saturation index; Δ: variation. *Significant differences between active and with p-value < 0.05

Discussion

This research focused on examining the effects of a four-week inspiratory muscle training (IMT) program on functionally independent older adults. The findings demonstrate significant improvements in maximal inspiratory strength, aerobic functional capacity, and lower limb resistance strength, along with a trend toward faster muscle reoxygenation.

Firstly, it is important to highlight the significant improvement in the functional independence of older adults following the 4-week IMT program. Specifically, significant improvements were observed in tests such as the standing bipedal test, the Biceps Curl test, and the 6-minute walk test.Principio del formulario

In the chair stand test, there was a 40% increase in the experimental group, indicating a significant improvement in the strength and endurance of the lower limbs. This is particularly relevant for older adults, as the ability to rise from a chair is an essential daily activity that correlates with independence and fall prevention. Improved ease in performing this task may translate into better quality of life and greater autonomy. In the Curl Biceps test, a 38% improvement was observed in the experimental group. This indicates a strengthening of the arm muscles, which are essential for activities such as lifting objects and performing household tasks. Maintaining strength in the upper body is crucial for functional independence and can help prevent injuries when performing everyday lifting movements such as carrying groceries, moving light furniture, or lifting grandchildren, which are often part of the daily activities of older adults. Finally, the 6-minute walk test showed a 41% improvement in the experimental group, reflecting a notable increase in aerobic functional capacity. The ability to walk longer distances without fatigue is a key indicator of cardiovascular health and endurance, enabling older adults to participate more actively in social and community life, which is vital for their mental and physical well-being.Principio del formularioFinal del formularioFinal del formulario These observations align with previous studies that have also reported positive correlations between inspiratory muscle training and increased autonomy in daily activities (Kurzaj et al., 2019; McCreery et al., 2021; Ferraro et al., 2022). Thus, it can be confirmed that IMT improves the ability to perform everyday physical tasks, which is crucial for maintaining independence in this population (Fortes et al., 2021), and is associated with better overall health and well-being outcomes.

The current findings underscore the significance of IMT not just in terms of the quality of life and self-sufficiency of older adults, but also in its direct impact on enhancing pulmonary and muscular function. Key indicators of significant improvement in the strength and endurance of the inspiratory muscles include a 44% increase in the S-index and a 33% increase in MIF in the experimental group. These changes have direct implications for improving the respiratory capacity of older adults, which may facilitate daily activities requiring pulmonary effort, such as walking briskly or climbing stairs.

Furthermore, although changes in FVC and FEV1 were modest, they reflect a positive trend in pulmonary function that merits exploration in future studies with larger samples and longer follow-ups. These data underscore the importance of including IMT in exercise programs designed to improve the respiratory health of older adults, potentially impacting their quality of life and independence. These findings on the positive impact of inspiratory muscle training (IMT) on pulmonary function and functional capacity in older adults are corroborated by previous research (Mehani, 2017; Martin-Sanchez et al., 2020). Indeed, the current results are in line with those reporting improvements in maximal inspiratory strength (Wickerson, 2019).Principio del formulario

The results related to muscle oxygenation, such as TSI and the difference between minimum and maximum saturation, did not show significant changes in the experimental group. This suggests that the 4-week IMT program did not have a marked effect on the oxygenation of tissues measured by NIRS. However, a 31% reduction in reoxygenation time (ΔTSIreoxy) might indicate a faster recovery of muscle oxygenation after exercise, a promising sign of potential improvement in the efficiency of the inspiratory muscles. Previous research also found no significant changes in muscle oxygenation(Kim et al., 2022), suggesting variability in the response to IMT depending on factors like health condition and age of the participants.Principio del formulario A recent systematic review revealed that IMT not only improves lung function by generating diaphragmatic hypertrophy and decreasing diaphragmatic sarcopenia, but also improves postural balance and cerebrovascular control, IMT has also been shown to improve autonomic control and endothelial function (Mello et al., 2024), this factor is mainly relevant as improvements in autonomic control could explain the improvements in muscle reoxygenation during recovery from exercise in this group.

In the case of improvements in physical fitness, despite these results, it is relevant to consider that the development of cardiorespiratory fitness and strength are good predictors of adverse events in older adults. Several studies have shown that multicomponent training improves general fitness, strength and cardiorespiratory fitness (Labata-Lezaun et al., 2023), so it is suggested to integrate IMT within this type of multicomponent exercise programmes to optimise gains in strength and fitness.

In summary, the evidence supports the usefulness of IMT in rehabilitation programs for older adults (Webb, 2022; Mętel et al., 2023). Improvements in functional capacity and pulmonary health can translate into better quality of life, suggesting that IMT should be considered as an integral strategy in managing health in this population. However, despite these results it is important to consider that while NIRS methodology is relatively inexpensive and easy to apply, there are limitations to its application that need to be considered, such as adipose tissue thickness, the unknown contribution of myoglobin, skin perfusion during exercise, variations in skin pigmentation and post-exercise vasodilatory effects, so optimal design should consider adjusting for these aspects (Jones et al., 2016). Finally, it is important to consider that this technology presents a good concordance with phosphorus magnetic resonance imaging to measure oxidative capacity at the muscle level and specifically mitochondrial function (Ryan et al., 2013).

Final del formulario

The main strength of the present study is that it is one of the first to analyze the effects of inspiratory muscle training on muscle resaturation with NIRS during physical exercise. However, it is not exempt from limitations, como un low sample size, the fact that heart rate variability was not analyzed to control the autonomic balance and that a direct assessment of VO2MAX was not performed or duration of follow-up. Therefore, these results should be taken with caution, which is why it is very important to continue research in this line of investigation. Future research could focus on longitudinal studies to understand the long-term effects of IMT in diverse populations, as well as explore the combination of IMT with other interventions to maximize the respiratory and functional health benefits in older adults. We hope to strength these limitations in future studies to better understand the effects of IMT on this population.

Conclusions

IMT could lead to improvements in maximal inspiratory strength, aerobic functional capacity and lower extremity endurance strength with a trend towards increased muscle resaturation velocity following exercise in older adults. These results provide new insights into the use of NIRS to identify the effects of IMT on peripheral muscle metabolism, an aspect to be considered by exercise and health science professionals when analyzing the effects of exercise on muscle oxygenation in this age group. Despite these advances, it is suggested to take these results with caution due to the limitations of the study and further research in this area is suggested.

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Datos de los/as autores/as y traductor/a:

Rodrigo Yáñez-Sepúlveda	rodrigo.yanez.s@unab.cl	Autor/a
Matías Monsalves-Álvarez	matias.monsalves@unab.cl	Autor/a
Marcelo Tuesta	marcelo.tuesta@unab.cl	Autor/a
Aldo Vásquez-Bonilla	alvasquezb@unex.es	Autor/a
Gladys Orellana-Lepe	gorellana@uvm.cl	Autor/a
Lilian Castro-Tapia	lcastro@uvm.cl	Autor/a
Pamela Ruiz	pamela.ruiz.a@upla.cl	Autor/a
Jacqueline Páez-Herrera	jacqueline.paez@pucv.cl	Autor/a
Jorge Olivares-Arancibia	jolivares@udla.cl	Autor/a
María Martínez-Olcina	maria.martinezolcina@ua.es	Autor/a
Ildefonso Alvear-Ordenes	i.alvear@unileon.es	Autor/a
Alejandro Martínez-Rodríguez	amartinezrodriguez@ua.es	Autor/a
Alejandro Martínez-Rodríguez	amartinezrodriguez@ua.es	Traductor/a