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Research article

Effects of 12 weeks of head-down strong abdominal breathing on motor and cognitive performance during dual-tasking in patients with chronic obstructive pulmonary disease: Study protocol for a randomised controlled trial

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ABSTRACT

Objective: Head-down training can affect behavioural and neurocognitive control while performing dual tasks (DT). Breathing training improves motor and cognitive performance in patients with chronic obstructive pulmonary disease (COPD). As a neurorehabilitation tool, functional near-infrared spectroscopy (fNIRS) has been demonstrated to be an effective method for detecting changes in brain activation during motor recovery, as well as monitoring patients' long-term progress during DT in motor and cognitive performance. However, no studies have examined the combined effect of head-down position and breathing exercises on motor and cognitive performance during DT. This study will employ a novel intervention involving head-down strong abdominal breathing training to investigate its effects on motor and cognitive performance during DT in patients with COPD aiming to inform future training modalities in the community and at home.

Methods: We will recruit participants from Anqing, China, through community announcements, bulletin board postings, WeChat, and offline visits and screen 72 patients with stable COPD, classified as Global Initiative for Chronic Obstructive Lung Disease (GOLD) I-II, by pulmonologists at the university hospital. All participants will be randomly assigned to the head-down strong abdominal breathing (tilt angle 0–30° on the inversion apparatus, respiratory rate 20–30 breaths/min), head-down training, and strong abdominal breathing training groups in a 1:1:1 ratio. The intervention will last 12 weeks, with sessions performed thrice weekly for 1 h.

Results: The primary outcomes will be motor-cognitive DT time, dual-task effects, correct responses to cognitive tasks, and gait characteristics assessed at baseline, 6 and 12 weeks of intervention. The patient's dorsolateral prefrontal cortex (PFC) will also be stimulated with fNIRS at wavelengths of 730 and 850 nm, with a sampling rate of 11 Hz, to record oxy-haemoglobin (oxy-Hb), deoxy-haemoglobin (deoxy-Hb), and total oxyhaemoglobin (total-Hb). Secondary

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outcomes will include pre- and post-intervention scales for dyspnoea, overall cognitive function, balance, and anxiety and depression.

Conclusion: Alterations in the PFC involved in attentional control, planning, and decision-making may partially explain cognitive and motor deficits (such as impaired balance and slower walking speed) in patients with COPD. This study may help to understand the effects of head-down strong abdominal breathing training on cognitive and motor performance under DT in patients with COPD and compare it with head-down training and breathing training alone. It may also help to determine whether it is a simple and effective form of exercise at home and in the community.

1. Introduction

Inflammation and structural changes in the airways of patients with chronic obstructive pulmonary disease (COPD) increase with disease severity and persist even after smoking cessation [1]. This can lead to many physiological abnormalities, including mucus hypersecretion, ciliary dysfunction, airflow obstruction and hyperinflation, gas exchange abnormalities, pulmonary hypertension, and systemic effects. Impaired cognitive function is an easily overlooked extrapulmonary consequence in patients with COPD. However, growing evidence suggests cognitive dysfunction in these patients [2]. Increased age and decreased educational levels are associated with cognitive dysfunction. Moreover, magnetic resonance imaging (MRI) has demonstrated that brain perfusion is altered in patients with COPD and clinical manifestations of cognitive dysfunction [3]. A direct link exists between inadequate cerebral perfusion and cognitive dysfunction. In a multicentre study of 302 patients with COPD and mild, moderate, and severe hypoxia [4], the frequencies of cognitive dysfunction were 27 % and 61 % in patients with mild and severe hypoxia, respectively. However, cognitive performance may also be affected in patients with normoxia. The cognitive function of patients with COPD may be affected in three ways: age-related reductions in blood flow, disease-related reductions in arterial oxygenation, and age- and disease-related reductions in physical activity [5–7]. McSweeny et al. [8] discovered that cognitive dysfunction in patients with COPD is closely related to impaired daily living function. The relationships between the many processes involved in everyday cognitive tasks are complex, but cognitive abilities are usually categorised into the domains of memory, learning ability, attention/concentration, abstract thinking, and problem-solving. Cognitive dysfunction reduces the level of activities of daily living and decreases medication and oxygen therapy compliance. Poor compliance increases the risk of acute exacerbations [9]. Therefore, studying the cognitive function of patients with COPD during rehabilitation programs is valuable.

Walking involves complex and unstable motor activities. Walking is not autoregulated because of the interaction between motor and cognitive systems. The prefrontal lobes primarily mediate executive function and play an important role in successful locomotion. The relationship between executive function and walking has been extensively studied through a dual task (DT) (simultaneous motor and cognitive tasks) paradigm [10]. The prefrontal cortex (PFC) plays an important role in postural, cognitive, and DT performance. In the past few years, Functional near-infrared spectroscopy (fNIRS) has been successfully used as a non-invasive technique to monitor brain activity in the whole-body activity paradigm [11,12], which utilises near-infrared light of specific wavelengths to detect changes in the concentration of oxy-haemoglobin (oxy-Hb) and deoxy-haemoglobin (deoxy-Hb) in the cerebral bloodstream over time, indirectly assessing the cognitive neural activity of the brain with good cost-effectiveness and eco-efficacy [13]. Additionally, fNIRS studies have revealed significant activation of the PFC, including the dorsolateral PFC, during walking [14], when responding to disturbances in an upright posture [15], and when performing a balance task in a semi-immersive virtual reality environment [16,17]. The PFC, particularly the dorsolateral PFC [18], is critical to a person's ability to selectively allocate (visuospatial) attention [19] as well as to integrate visual and proprioceptive information [20] to maintain or restore postural stability.

Breathing exercises, such as maximal expiratory training [21], respiratory resistance training [22], inspiratory muscle training [23], and pilates [24], can effectively improve dynamic balance in older adults, leading to improved walking speed and inspiratory muscle function [23,25]. Breathing exercises are often combined with exercises for the limbs or trunk, such as planks, elbow-toe exercises, and postural stabilisation exercises. As the respiratory muscles can be used for both respiration and postural control, combining exercises can have a synergistic effect. A relationship exists between the demands of tasks, such as posture or limb movements, and the respiratory demands of the respiratory muscles (diaphragm, internal obliques, and transversus abdominis). However, the contributions of the transversus abdominis and diaphragm to spinal stability may be compromised as respiratory demands increase, as in certain sports or respiratory disorders [26]. These basic studies have suggested the principle of performing exercise in conjunction with proper posture and breathing to prevent injury and enhance physical function. Furthermore, the relationship between pulmonary impairment and cognitive decline has been demonstrated in some studies [27,28], suggesting the negative impact of respiratory insufficiency on cognitive domains such as memory and learning, attention, psychomotor speed, visuospatial ability, executive functioning, and verbal skills [29,30]. Regular respiratory exercise is an effective intervention for maintaining cognitive function. For example, Ferreira et al. [31] observed that respiratory training promotes blood oxygenation and enhances brain function, improving cognitive function and memory. Lu et al. [32] discovered that 16 weeks of qigong training reduced the rate of errors made in the auditory Stroop test under DT conditions and improved postural control. However, few studies have investigated the effects of respiratory training on motor and cognitive performance during DT in older adults (especially in those with certain respiratory diseases).

Head-down training is a type of resistance training against gravity that was first introduced in 1694 as a medical exercise rehabilitation treatment and is mainly used in clinical diagnosis, treatment, intervention, and other studies [33,34]. Common methods for

head-down training include unarmed inversion, hand-head triangle inversion, inversion trainer-assisted inversion, ankle or knee inversion training, inversion bed-assisted head-down training, aerospace simulation of weightlessness in head-down −6°, −10°, −30°, −45°, −60°, −80°, −90°, and other multiple-angle training. Depending on the purpose of the study, head-down position training includes dynamic, static, and combined dynamic and static training. Dynamic training, such as trampoline, diving training, air inverted position, and gymnastics, involves the human body flip action. Static training includes basic skills in gymnastics, timed handstand, aerospace field, and different angles of head-down position. Static and dynamic training includes the combination of static and dynamic inverted training as in traditional Chinese acrobatics, static inverted position as in Indian yoga, and dynamic respiratory regulation. Most of the current studies in the aerospace field use head-down bed rest to simulate spaceflight. One short-term (16 days) and two long-term (60 and 70 days) studies measured DT performance during head-down bed rest. Regarding behavioural outcomes, neither short- [35] nor long-term [36,37] studies revealed impaired performance during or after exposure to head-down bed rest. The behavioural results revealed no impairment and functional MRI results indicated an increase in brain activation associated with periods of head-down bed rest during DT. This may stem from the differences in task complexity and cognitive load among the DT applied. Increased DT costs may be due to adapting to a bedrest environment, which may limit resource availability. These changes may arise from the physiological, perceptual, and psychological effects of bed rest. First, intravascular and extravascular fluids shift toward the head and upper body when the participants remain in head-down bed rest for a sustained period. Axial body unloading and potential sensory changes that occur during head-down bed rest may deplete the available resources. Adaptive changes in the brain are also challenged, affecting DT performance. Second, participants' sensory-motor performance changes before and after head-down bed rest, and the resource demands of this process may limit their DT ability. However, these studies were all conducted under head-down static conditions and may have yielded different results for head-down dynamic conditions. For example, 12 weeks of yoga practice in sitting and supine postures exhibited a statistically significant difference in DT performance [38]. The timed up-and-go test (TUG) exhibited improvement but was not sufficient to reach clinical significance. The small sample size may have hindered the examination of clinical significance, with only 13 individuals completing the study in the initial screening. Therefore, further exploration of their clinical significance is required.

Strong abdominal breathing in the head-down position proposed by Sun et al. [39] refers to abdominal breathing that resists gravity's resistance while maintaining an appropriate depth of exhalation and rapid inhalation. This technique has been demonstrated in preliminary studies to positively affect cerebral arterial blood flow velocities in all periods in young individuals [40,41]. Changes in body position affect cerebral blood flow in older adults similarly, reducing psychological stress and improving sleep quality [42]. The inspiratory muscles of the human body are more developed than the expiratory muscles. The body's oxygen demand increases during strenuous exercise, making inhalation an urgent instinctive need. Therefore, increasing the expiration depth during exercise should be a focus of respiratory regulation [43]. Despite the high efficiency of deep and slow breathing, this form of respiration cannot satisfy the oxygen requirement in strenuous exercise, whereas relatively shallow and fast respiration can fulfil the need. Therefore, deep and slow breathing is suitable for fitness and rehabilitation in middle-aged and elderly individuals, people with relatively weak physical conditions, or those with certain diseases. Shallow and fast breathing is more suitable for young, healthy individuals. However, as a conscious breathing exercise, it can be applied to any group of people, with the depth and frequency of breathing varying from person to person. Previously, we discovered that high-intensity exercise (up to a certain threshold intensity) had greater physiological benefits than low-intensity exercise. Head-down strong abdominal breathing, as a high-intensity exercise intervention, may have a positive impact on patients with COPD, partly depending on the relationship between the intensity of the training and its effectiveness in inducing training effects on the exercising muscles.

The present study builds on previous research that examined both motor and cognitive performance under DT conditions by incorporating either breathing training alone or head-down training. Breathing training positively affects DT performance, and dynamic head-down training conditions improve dual-task performance. However, to our knowledge, no studies have combined the two to explore the effects of DT on motor and cognitive performance; therefore, our study is novel. Strong head-down abdominal breathing is inexpensive, simple to perform, and requires minimal space. It reduces psychological stress, improves sleep, and positively affects cerebral blood flow in older adults. Concurrently, head-down strong abdominal breathing mimics high-intensity exercise, which leads to greater exercise capacity and improved productivity in people with COPD. In patients with mild COPD [44], high-intensity exercise performed twice weekly for 3–6 months significantly improves exercise capacity, muscle mass, and quality of life. We hypothesised that strong head-down abdominal breathing may positively impact DT in patients with COPD. Furthermore, in these patients, a relationship exists between lung function decline and cognitive function. Under DT conditions, patients with COPD experience greater difficulty performing more complex walking processes, indicating hyperactivation of the PFC [45] and greater variability in stride duration [46]. Most of the current studies have focused on the effects on patients with COPD during DT or explored the postural aspects through DT training, with fewer studies on cognitive and motor performance under DT after the intervention. Furthermore, executive function during walking is primarily mediated by the prefrontal lobe. The indirect assessment of cognitive neural activity by monitoring brain activity using fNIRS has been demonstrated. fNIRS is more sensitive to brain regions during DT, particularly the dorsolateral PFC, which is involved in attentional control and executive function, including memory, planning, and decision-making [47]. Therefore, this study aimed to compare the potential benefits of 3 months of head-down strong abdominal breathing training, head-down training, and strong abdominal breathing training on the performance of patients with COPD in motor-cognitive DT under a new modality for pulmonary rehabilitation tools.

2. Materials and methods

2.1. Design

This study is a single-centre, assessor-blinded, randomised controlled trial. Participants will be recruited at non-governmental organisation community centres in China. COPD diagnosis will be confirmed by a pulmonologist at the university hospital based on pulmonary function measurements (using a portable hand-held spirometer) and assessment of lifetime smoking and occupational exposures. If any uncertainty arises about the diagnosis of COPD, the study team will contact the general practitioner at the university hospital. Written informed consent will be obtained from all participants before measurements are taken. The study will be conducted in accordance with the principles of the Declaration of Helsinki. The Ethics Committee of Anqing Normal University approved this

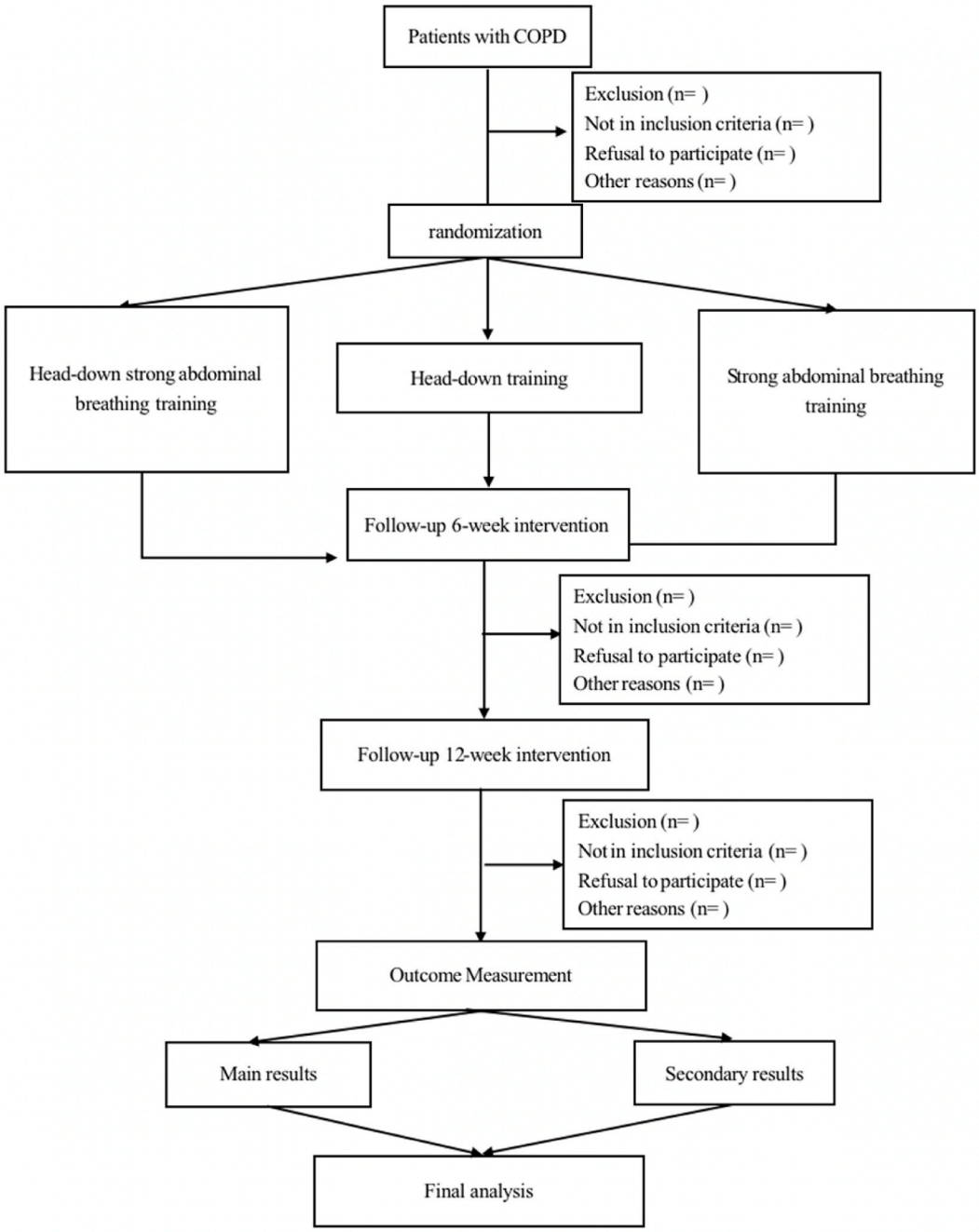

Fig. 1. Experimental procedure.

project on 4 December 2023 (approval number: ANU2023002), and it was registered with the China Clinical Trial Registry (trial registration number: ChiCTR2400080452). All participants will be randomised into a head-down strong abdominal breathing training group, a strong abdominal breathing training group, and a head-down group and will undergo the intervention for 12 weeks each. Motor-cognitive DT time, dual-task effects (DTE), correct responses to cognitive tasks, and gait characteristics will be measured at baseline and after 6 and 12 weeks of intervention. Simultaneous monitoring of oxy-Hb, deoxy-Hb, and total haemoglobin (total-Hb) metrics using fNIRS will serve as the primary study outcome. We will explore the effects of changes in head-down strong abdominal breathing training on cognitive performance, including prefrontal activity and motor ability, during DT in patients with COPD, providing a new possibility for pulmonary rehabilitation in such patients. This study aims to complement previous research on the effects of head-down position training or breathing training on motor and cognitive performance DT. Additionally, because DT is more representative of daily life, it is socially valuable to explore the effects of strong abdominal breathing in the head-down position on DT performance in patients with COPD. The results of the data analysis will be published in another paper. The experimental procedure is illustrated in Fig. 1.

2.2. Indicators

All measurements will be made in a temperature-controlled laboratory (20–22 °C; humidity <70 %). Tests and phases will be scheduled at similar times of the day (between 9:00 a.m. and 4:00 p.m.) to minimise the potential effects of daily variations. Participants will be advised to refrain from drinking, smoking, eating, and strenuous exercise 2 h prior to the measurement. The test-

Table 1
Study measures and outcomes to be collected.

Variable	Baseline	6- week follow-up	12-week follow-up
Primary outcomes			
oxy-Hb	X	X	X
Deoxy-Hb	X	X	X
Total-Hb	X	X	X
stride length	X	X	X
Step width	X	X	X
Cycle Duration	X	X	X
Stride length	X	X	X
Velocity	X	X	X
Stride length coefficient of variation	X	X	X
Cadence	X	X	X
DTE	X	X	X
Total dual-tasking time	X	X	X
Cognitive task correctness	X	X	X
Secondary outcomes			
Modified Medical Research Council Scale (mMRC)	X	X	X
St George's Respiratory Questionnaire (SGRQ)	X	X	X
COPD Assessment Test (CAT)	X	X	X
Montreal Cognitive Assessment (MoCA)	X	X	X
Hospital Anxiety and Depression Scale	X	X	X
Berg balance scale (BBS)	X	X	X
Anthropometric measures			
Sex	X		
Age, years , ± SD	X		
Weight	X		
Charlson Comorbidity Index	X		
Height	X		
Body Mass Index, kg m^2	X		
Self-reported measures	X		
FVC	X	X	X
FEV_1	X	X	X
FEV_1/FVC%	X	X	X
FEV_1% expected	X	X	X
DLco	X	X	X
DLco/VA [48]	X	X	X
MIP	X	X	X
MEP [49]	X	X	X
$PaCO_2$, mmHg	X	X	X
PaO_2, mmHg	X	X	X
Smoking status	X		
Pharmacologic treatment	X	X	X

oxy-Hb: oxy-haemoglobin; Deoxy-Hb: deoxy-haemoglobin; Total-Hb: total oxyhaemoglobin; DTE: dual-task effect; DLco: diffusion lung capacity for Carbon Monoxide; VA: alveolar ventilation; MIP: Maximum inspiratory pressure; MEP: Maximum Expiratory Pressure; $PaCO_2$: arterial carbon dioxide partial pressure; PaO_2: Partial Pressure of Oxygen; FEV_1% expected: volume of 1-s forceful expiration as a percentage of predicted value; FVC: forced vital capacity; FEV_1: Forced expiratory volume at 1 s; FEV_1/FVC%: Ratio of expiratory volume in 1 s to expiratory lung capacity.

related indicators are presented in Table 1. See annex 1 and 2 for relevant support information.

2.3. Participants

2.3.1. Recruitment and selection

Enrolment in the trial will begin on 2 February 2024 and is scheduled to continue through 31 May 2024. The intervention phase and final follow-up assessment are expected to be completed by 30 September 2024. The investigator will inform all participants who meet the inclusion criteria regarding the purpose, content, possible risks, and benefits of this study. If the participants wish to participate in the study, the recruiting researcher will speak with them in detail to confirm that they meet the inclusion and exclusion criteria. All participants will retain their original documentation, a copy will be filed with the case report form, and all medical records and assessment data collected from the participants will be securely stored on the researcher's encrypted, removable hard drive. Only authorised researchers will have access to the trial data.

2.3.2. Inclusion criteria

1. A confirmed diagnosis of COPD according to the Global Initiative for Chronic Obstructive Lung Disease (GOLD) diagnostic criteria (1-s forced expiratory volume (FEV_1)/Forced Vital Capacity (FVC) < 70 %) [50].
2. Patients classified as stable GOLD I-II with no deterioration for at least 4 weeks before intervention;
3. An age range of 50–80 years;
4. Patients who are not on long-term oxygen therapy at home;
5. Not participating in another regular exercise program.

2.3.3. Exclusion criteria

1. Inability to complete the questionnaires owing to cognitive impairment;
2. Difficulty in completing the cardiopulmonary exercise test or the 6-min walk test;
3. Severe cardiovascular or cerebrovascular disease, hepatic or renal insufficiency, epilepsy, and other neuropsychiatric disorders, etc., assessed by the investigator as not easily amenable to this study;
4. Severe combined lung cancer, tuberculosis, interstitial fibrosis, severe alveoli, pneumothorax, history of thoracic and abdominal surgery, etc., which the investigator considers to affect the observation of the efficacy of the treatment or the risk of performing pulmonary rehabilitation exercises
5. Pleural disease or thoracic deformity;
6. Severe cognitive impairment/dementia (Montreal Cognitive Assessment (MoCA) score <17) or neuropsychiatric symptoms in other diagnoses.
7. Planned thoracic surgery within the next 3 months

2.4. Randomisation and blinding

Randomisation will be performed by an investigator not involved in patient recruitment, assessment, or training. Randomisation will be ensured using computer-generated random numbers in SPSS V.27.0, assigning subject identifiers (random assignment numbers) to participants who meet the inclusion and exclusion criteria and assigning them to the three groups in the same 1:1:1 ratio according to the generated random number table. We will use opaque envelopes containing the numbers for participant randomisation and keep them in the sole custody of the researcher until the end of the trial to keep the assignments hidden. The investigator will submit a written commitment not to disclose the allocation sequence.

Full blinding procedures will not apply to this study. Owing to the nature of the study, the trainers and patients will not be blinded. Patients will be aware of the existence of the three intervention groups; however, they will not know the exact contents of the other two. Patients in all three groups will not be treated in the same physical therapy setting at the same time. Using assessor blinding, the assessor will not know what type of treatment the participant is receiving but will only perform tasks relevant to assessing the participant. Prior to all assessments, the trainers and patients will be reminded not to disclose their group assignments to the assessor. If it is not possible to blind the outcome assessor (i.e., if the participant discloses their assignment), a second assessor can intervene and perform the assessment on another day. We will provide standardised instructions to evaluators through Unified Learning and Practice training within 1 week before the initial and final evaluations.

2.5. Sample size

We performed a priori analyses to determine the optimal sample size using the G*power 3.1.9.7 analysis program. Primary outcome measurements have never been determined in previous studies. We expected to achieve a medium effect size of 0.25, while setting a power of 0.95 and a significance level (α) of 0.05. With 54 patients required for the calculation, and a 30 % non-adherence rate for patients in our region, we recruited 24 patients in each group, for a total of 72 patients.

2.6. Intervention

2.6.1. Head-down strong abdominal breathing

Participants will undergo strong head-down abdominal breathing training for 12 weeks (Fig. 2). In the intervention, a 5-min warm-up acclimatisation will be performed prior to exercise, followed by 50 min of head-down strong abdominal breathing training and 5 min of relaxation with stretching exercises (Table 2). In patients with COPD, achieving very high training loads in a continuous training program is challenging, possibly because of intolerable dyspnoea [51]. In contrast, interval-based training programs offer patients with COPD the opportunity to achieve very high training loads with less dyspnoea [52]. Therefore, in this study, a frequency of 3 min of respiratory training with 2 min of rest will be used for 10 cycles. The rate of each breath will be 20–30 breaths/min (metronome cue) [53,54]. We will set the head-down angle to 0–30° (inverted dual-purpose gymnasium patent application no. 201821510570.5) [55] and follow the principle of individualisation and gradual progression. Each participant will start training with powerful abdominal breathing from a lower-angle head-down position to gradually adapt to the head-down position. The head-down position angle will be 0° at the beginning and thereafter increased by 5° per week, which can be changed to 10° per week if the patient has a Borg self-perceived exertion rating of 6–8 during training (Note: Informed consent was obtained from all investigators in the figure).

2.6.2. Head-down training

Patients will receive the same number and frequency of breathing exercises adapted from the head-down strong abdominal breathing training described above, performed with normal breathing and at the same head-down angle as the head-down strong abdominal breathing training group. The head-low training will be performed in a manner similar to the head-low bed rest in simulated airline flight studies [56], with no intervention other than head-low rest. We will explore the effect of the prolonged head-down position on dual-task-related outcomes in patients with COPD.

2.6.3. Strong abdominal breathing

The patient adopts a comfortable sitting position, relaxes the whole body, places the left hand on the chest and the right hand on the navel, and is asked to inhale rapidly through the nose and consciously increase the depth of abdominal breathing. This is performed three times a week for 1 h each time. The same will be used for breathing training for 3 min, rest for 2 min, for a total of 10 cycles, with a respiratory rate of 20–30 breaths/min (metronome cue). The intervention period is 12 weeks. The strong abdominal respiratory training explores the effects of long-term head-down rest removal on dual-task-related indicators in patients with COPD.

2.7. Intensity control

To control the intensity of strong abdominal breathing training, the movements of the trainees will be strictly controlled and calibrated during the training using a metronome and pressing the abdomen with both hands to achieve effective training. A researcher will supervise the exercise, and the intensity will be controlled by objective and subjective indicators. The objective indicators include monitoring the heart rate at all times during the three intervention training periods, exercising at an intensity based on the target heart rate (220-age) × (0.65–0.85) [57], and ensuring that the increase in heart rate and respiratory rate is less than 20 beats/min and 5 beats/min, respectively, after their exercise [58]. Subjective indicators include the degree of self-exertion grading and subjective feelings. Self-exertion grading will use the Borg self-exertion grading, with a score of 11–13 points. Sweating without obvious discomfort during and after exercise will be considered appropriate.

2.8. Commitments

We will conduct a protocol-compliant analysis, and participants in all three groups will have completed 70 % of their COPD

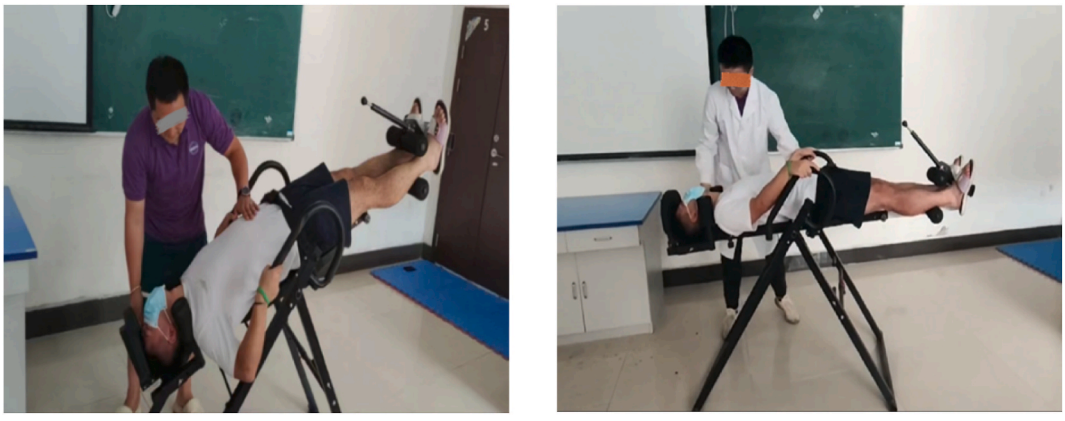

Fig. 2. Head-down strong abdominal breathing training chart.

Table 2
Warm-up protocol.

Time	Exercises	Intensity	Progression
Warm-up and Relax (duration 5 min)	Standing Chest stretch Leg swing Squats Leg curl Abdomen stretch Ankle movement	Non-specific intensity Purpose: Reduce muscle soreness improve blood circulation Prevent lactic acid accumulation	None

rehabilitation program to be included in the protocol analysis. Ultimately, we will check all data for errors and missing data before they are entered into a spreadsheet database in Excel, and all required data will be exported to the relevant statistical software, SPSS V.27.0. The principal investigator will have access to the entire dataset, and the co-investigators and the steering committee will have access to random audits as required. All paper copies will be anonymised and locked in a filing cabinet to ensure confidentiality. Additionally, to standardise procedures across participants, the three interventions will be conducted thrice per week, on alternate days, and uniformly from 9:00 a.m. to 10:00 a.m. to reduce intervention variability and enhance the reliability of the results.

2.9. Researchers' training

We will develop a five-item adherence score to assess researcher competence. The assessment items will include whether the researcher (1) can apply simple and direct instructions; (2) can respond to unexpected events; (3) provides verbal positive reinforcement; (4) completes documentation for the patient; and (5) is able to adjust tasks accordingly to the patient's abilities. Each researcher's adherence will be scored by a professional researcher from our research team who will be visiting the first and final session of the training program.

2.10. Safety

Pre-experiments will be conducted during the recruitment phase to finalise the head-down training angles, and all head-down angles will be determined by the researchers in consultation with clinicians. Additionally, prior to all exercises, we will assess the history and existing chronic diseases, risk factors, and treatment options. Patients should be routinely evaluated for their ability to perform activities of daily living, quality of life, and exercise function, including cardiopulmonary function assessment, muscle strength, and muscle endurance assessment, and heart rate and blood pressure should be monitored during exercise. If the patients experience symptoms such as shortness of breath, chest tightness, and palpitations during exercise, they should terminate the activity immediately, and if it is not relieved after resting, they should be sent to the hospital in time for medical treatment to ensure patient safety. The patients should move slowly during the activity, and each breathing action should be performed with one breath and one inhalation. In the post-exercise assessment, the patients' heart rate and blood pressure will be monitored, and timely adjustments will be made in case of any discomfort. The Ethics Committee will review data on participant characteristics and adverse events in the treatment group at regular intervals during the study. For patients who are unable to continue training for other reasons, the investigator will record the reason for withdrawal in the case report form, keep in touch with the participant and complete the assessment if possible, and complete the end-of-trial form. Patients and their families will be educated about the disease before the start of the trial. For patients with high-risk factors such as falls, their families will be instructed to monitor the patient's activities and physical changes.

2.11. Statistical analysis

The oxy-Hb, deoxy-Hb, and total-Hb data of the dorsal outer PFC will be acquired using an fNIRS device and processed using fnirSoft. Statistical analyses will be performed using SPSS v.27.0, and data normality will be tested using the Kolmogorov–Smirnov method [59]. We will check for outliers using the Tukey Fences method, removing values less than Q1 - 1.5*IQR and greater than Q3 + 1.5*IQR (Q = quartiles; IQR = inter-quartile range) [60]. We will also assess and summarise the extent and patterns of missing data and, where appropriate, use appropriate methods (e.g., regression estimation using baseline data) to assess any impact that missing data may have on the conclusions.

Statistical descriptions of general information, including count data such as sex and smoking status, will be described statistically in terms of frequencies and percentages, and measures such as age and lung function will be expressed statistically in terms of means and standard deviations or quartiles. General information on the three study groups, including count data such as sex and smoking status, will be statistically analysed using the chi-square test or Fisher's exact probability method. Data such as age, height, and weight will be statistically analysed using the independent samples *t*-test or Mann–Whitney U rank sum test. For continuous data, repeated-measures analysis of variance (ANOVA) will be used to test for within-group differences, one-way ANOVA will be used to test for between-group differences, and the Bonferroni test will be used for post-hoc multiple comparisons [61]. Differences will be analysed using the chi-squared test for categorical data. Additionally, the effect size (ES) for each outcome measure will be calculated according to the following formula: ES = (mean pre value - mean post value)/SD pre value (ES = (mean pre value - mean post value)/SD pre value). The ES is a measure of the treatment effect that helps determine whether a statistically significant difference is actually meaningful.

According to Cohen's [62] guidelines, an ES of 0.20 indicates a small effect, an ES above 0.50 indicates a medium effect, and an ES above 0.80 indicates a large effect. Linear regression models will be used to investigate whether the primary outcomes are associated with these psychosocial or physiological parameters, using the primary study outcomes (oxy-Hb, deoxy-Hb, total-Hb, and motor-cognitive DT outcomes) as dependent variables and dyspnoea, cognitive functioning, balance, and anxiety and depression scores as potential mediator variables. Separate exploratory models will be developed for each primary outcome to gain insight into the underlying mechanisms of influence. $P \leq 0.05$ and $p \leq 0.01$ will be considered statistically significant.

3. Results

3.1. Basic characteristic

The demographic and clinical characteristics of all participants at baseline, including age, sex, height, weight, body mass index, marital status, educational status, smoking status, years of COPD, morbidity index (Charlson morbidity index), and medications, will be recorded using a questionnaire. Pulmonary function measurements will be performed by a pulmonologist or respiratory nurse at baseline, at 6- and 12-week follow-ups. We will use clinically approved spirometry equipment (MasterScreen, 6-161028-0019) through the hospital, with reference to the American Thoracic Society/European Respiratory Society guidelines for the measurement of FEV_1, FVC, diffusion lung capacity for carbon monoxide (DLco), diffusion lung capacity for carbon monoxide/ventilation alveolar (DLco/VA), maximum inspiratory pressure, and maximum expiratory pressure. Laboratory physicians will collect data from the earlobes, including the arterial partial pressure of oxygen, arterial partial pressure of carbon dioxide, and arterial oxygen saturation, using a blood gas analyser (SIEMENS, RAPIDLab348EX) after sitting for at least 10 min. These results will be entered into the hospital registration system.

3.2. Primary outcome

Primary outcomes will be measured at baseline and at 6 and 12 weeks after the intervention. Outcome test metrics will include motor-cognitive DT time, DTE, the correct response rate in cognitive tasks, gait characteristics, and fNIRS stimulation of the patient's dorsolateral PFC, as indicated by oxy-Hb, deoxy-Hb, and total- Hb levels. The TUG test is effective for patients with COPD [63]. We will assess the mobility and gait speed in single-task (ST) and DT conditions using the TUG. (i.e., cognitive-dual task time-up-and-go test (CO-DTTUG) and motor-dual task time-up-and-go test (MO-DTTUG)).

3.2.1. ST and DT test procedure

The single task time up-and-go test requires the participants to sit on the edge of an armless chair (sitting height 49 cm). After hearing the command "3, 2, 1, start," they are instructed to stand up, walk forward 3 m, turn around, and return to the chair to sit; the total test time is recorded, and a frontal video of the participant is also recorded at the endpoint.

The CO-DTTUG requires participants to stand up from their chairs, walk forward 3 m, turn around, and return to their chairs to sit. While walking, they perform a count out loud, subtracting seven consecutively from a randomly selected number between 80 and 100 [21]. The total time of the walking test and the accuracy of the cognitive task are recorded. The frontal video of the participants is recorded at the endpoint.

The MO-DTTUG requires participants to stand up from a chair, walk forward 3 m, turn around, return to the chair to sit, and hold a glass (10 cm in diameter, 11.5 cm in height) filled with water (1 cm from the rim of the glass) while walking. The total time of the test and a frontal video of the participant at the endpoint are recorded simultaneously. The same task was performed three times and an average was taken.

3.2.2. Testing of gait indicators

Gait metrics will be measured using a SAB-GAIT (SAB-FAIT Information Technology (Beijing) Co., Ltd.) 3D gait analysis system. Gait indicators include the step width, step speed, step frequency, stride time, stride length, and stride length under the ST and DT conditions. The shorter the stride time, the better the gait performance, and the larger the step width, stride frequency, stride length, and stride length, the better the gait performance. Gait variability is a marker of gait stability and fall risk [64,65]. As an outcome measure, we calculated the coefficient of variation of stride length using the formula [(SD/Mean)*100] [64], where the smaller the CV value, the better the walking pattern.

a. Stride width: the width between the midline of both feet;
b. Cycle duration: the time required to complete a walking cycle, such as the time elapsed from the first landing of the heel of the right foot to the second landing.
c. Velocity: the distance walked per unit of time;
d. Cadence: the number of steps walked per unit of time;
e. Step length: the distance measured from the point of contact of one foot (heel or toe) with the ground to the point of contact of the opposite foot with the ground during walking;
f. Stride length: the longitudinal straight-line distance between two points where the heel of the same side of the foot strikes the ground twice in a row, and the general lengths of the left and right strides are equal.

3.2.3. Cognitive task indicator

For CO-DTTUG, the cognitive task consists of counting down in threes from a random number between 80 and 100 to count the total number of cognitive responses, recording the number of correct and incorrect responses, and calculating the percentage of correct answers. To analyse DT interference, the DTE [66] of the gait performance will be calculated (Equation (1)). Between any two tasks, the participant will walk back to the starting position and will be given a rest period of random duration (1–2 min), during which instructions for the next task will be provided. Between tasks, the participants will be able to sit down and rest until they are ready to continue the trial. Before starting any task, we will ensure that all participants stand for at least 1 min to minimise blood pressure fluctuations after standing.

$$\mathrm{DTE} = \{(\text{dual task} - \text{single task})|\text{single task}\} \times 100\% \tag{1}$$

3.2.4. fNIRS measurements

A portable near-infrared brain functional imaging device (NirSmart; Danyang Huichuang Medical Equipment Co., Ltd., China) will be used to record the cortical activation states during each ST and DT. The system consists of an NIR light source (light-emitting diode, LED) and an avalanche photodiode with high sensitivity as a detector with wavelengths of 730 and 850 nm, respectively, and a sampling rate of 11 Hz. The advantages of this system are its ease of operation and high immunity to motion disturbances [67,68], which allows for real-time dynamic observation of cerebral cortex activity. There are 32 fNIRS channels. The average distance between the light source and detector is 3 cm, and the device consists of a head cap, optical fibre, signal collector, transmission module, and host computer. The head cap is wrapped around the participant's head such that the transmitter and receiver probes fit snugly on the surface of the patient's scalp. Before commencing the formal task, the participant will be given an fNIRS electrode cap to wear in accordance with the position marked by the system. After wearing, the general information of the participant will be inputted. Afterwards, the fNIRS signal debugging phase will be performed to make the electrode cap comfortable to wear and ensure that the signals of each channel are good. After debugging is completed, the formal task phase will be entered. Participants will be instructed to perform different tasks according to randomisation, during which the fNIRS device will be kept to continuously collect their cortical oxy-Hb, deoxy-Hb, and total-Hb concentrations. At the end of the task, the skullcaps will be removed (Fig. 3).

3.2.5. fNIRS signal processing

NirSpark software (Danyang Huichuang Medical Equipment Co., Ltd., China), which has been used several times in previous experiments, will be used to analyse the fNIRS data. The detailed processing steps are as follows.

(a) De-artifactting: spline interpolation is used to remove motion artefacts (Motion) [69], which manifest as pulsed or cliff-like signal jumps caused by the relative sliding of the scalp and probe. Automatic de-artefacts will be selected during pre-processing using the NirSpark software. A 0.5-s time window detection is performed on the data. In a certain time window, if the difference between the maximum optical density and the minimum optical density is greater than six times the overall standard deviation value or if the difference between the maximum optical density and the minimum optical density is 0.5 times its own, it will be judged as the presence of motion artefacts. The algorithm of spline interpolation will be applied in that time window to correct this part of the data.

(b) Band-pass filtering (filter): after the first step of pre-processing to remove artefacts, the NirSpark software will perform band-pass filtering between 0.01 and 0.2 Hz on the raw data to eliminate the effects of physiological noise (e.g., respiration, cardiac activity, and low-frequency signal drift).

(c) Signal conversion (haemo): the previously processed signal data will be converted to oxy-Hb, deoxy-Hb, and total-Hb concentrations in mmol/L × mm using the modified Beer–Lambertlaw [70].

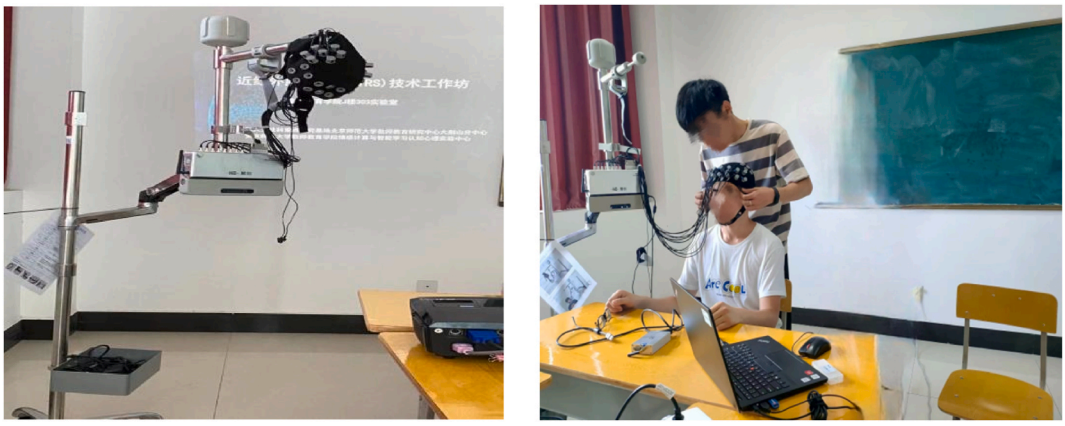

Fig. 3. fNIRS test prep diagram.

(e) Characteristic value (feature) calculation: Considering that changes in cortical oxy-Hb concentration often have a lag of 2–5 s, to ensure the accuracy of the final cortical oxy-Hb mean value for a task type, the difference between the first 5 s mean value at the beginning of the removal minus the baseline mean will be calculated as the characteristic value of the final result, that is, the mean value).

3.3. Secondary outcomes

Secondary outcomes will be measured at baseline and after 6 and 12 weeks of intervention. The outcome test metrics include pre- and post-intervention assessments of dyspnoea, overall cognitive functioning, balance, and anxiety and depression.

Modified Medical Research Council (mMRC): The mMRC was first proposed by British scholar Fletcher [71] et al., in 1959 to measure dyspnoea. The retest reliability is 0.99, and Cronbach's a coefficient is 0.80. A 5-level scoring method will be adopted: dyspnoea felt only during strenuous activities, level 0 (0 points); shortness of breath when walking fast on level ground or climbing a small slope, level 1 (1 point); walking slower than peers on level ground or needing to stop and rest because of shortness of breath, level 2 (2 points); needing to stop and gasp for breath after walking 100 m on level ground or after a few minutes, level 3 (3 points); inability to leave the room because of obvious dyspnoea or shortness of breath when changing clothes, level 4 (4 points). China's guidelines for the diagnosis and treatment of COPD (2013 revised edition) use mMRC as an assessment tool for dyspnoea severity [72]. mMRC grades 0, 1, and 2–4 are moderate, moderate, and severe, respectively.

Montreal Cognitive Assessment (MoCA): The MoCA, a specialised screening tool for mild cognitive impairment developed by Nasreddine et al. and translated into Chinese by Wang et al. [73] in 2007, has high sensitivity and specificity in evaluating mild cognitive impairment. The scale has a retest reliability of 0.86 and a Cronbach's coefficient of 0.82. The scale consists of eight dimensions: visuospatial, executive ability, naming, attention, language ability, abstract ability, delayed recall, and orientation, and has a total score of 30 points. Scoring less than 26 points is recognised as a cognitive functioning deficit (with the total score increased by 1 point if the time of receiving cultural education is less than 12 years), and a lower score indicates worse cognitive function.

Hospital Anxiety and Depression Scale (HADS): The HADS has two subscales with Cronbach's alpha coefficients of 0.76 and 0.7904 [74], which have a high degree of reliability and are used to assess anxiety (HADS-A) and depression (HADS-D). There are 14 items, seven for each subscale, on a 4-point Likert scale (0–3). All single-item scores are totalled for the diagnosis of anxiety, and all double-item scores are totalled for the diagnosis of depression. The score range for each subscale is 0–21, and the total score for each subscale is used to determine the degree of anxiety and depression. A total score of 0–7 is considered normal, a total score of 8–10 indicates mild anxiety and depression, a total score of 11–14 indicates moderate anxiety and depression, and a total score of 15–21 indicates severe anxiety and depression.

Berg Balance Scale (BBS): a 14-item test that examines the performance of a participant in different movement situations. Specific test movements include sitting, standing up, walking, and bending down to pick up objects, and multidimensional standing movements such as standing with feet together, standing with eyes closed, standing with feet in front of and behind each other, and standing on one foot. Domestic scholars, such as Jin Dongmei, who applied the scale in Chinese, indicated that the BBS was used to assess the balance function of Chinese patients with good reliability and sensitivity [75] and quantitatively reflected balance function. A large body of evidence supports the application of this scale in patients with COPD, and researchers often use it to measure differences in balance function values before and after pulmonary rehabilitation in these patients.

COPD assessment test (CAT): The scale's Cronbach's alpha coefficient is 0.88, which is a reliable and valid indicator used to assess the degree of dyspnoea in patients with COPD [76]. Compared with other scales for evaluating pulmonary function in patients with COPD, the CAT scale is relatively simple and can be completed in 2–3 min, including eight items such as cough, shortness of breath, sleep condition, and ability to perform activities of daily living, with higher scores representing poorer lung function in patients.

St George's Respiratory Questionnaire (SGRQ): The SGRQ is one of the most widely used special scales in assessing the quality of life in patients with COPD and can also be applied to the assessment of their condition, prognosis, and efficacy [77]. It is considered the gold standard for measuring the quality of life and the degree of health impairment in patients with respiratory diseases. Lu et al. [78] discovered that the SGRQ has the highest correlation with COPD patients in China compared to other scales and can better reflect the actual situation of patients. The scale consists of 50 questions, including three parts: symptoms (frequency and severity of occurrence), activities (activities that cause shortness of breath or restriction of respiration), and impact on daily life (social competence and mental health). Lower scores represent a better quality of life.

4. Discussion

Early prevention strategies (prior to the establishment of permanent cognitive impairment) can be effective in improving routine and DT gait performance in individuals at a higher risk of cognitive impairment, as well as in maintaining functional independence, reducing the risk of falls, and alleviating the increasing burden of mobility impairment and dementia on the healthcare system. A growing body of evidence suggests [79] that habitual participation in exercise programs may improve DT gait parameters. Our use of head-down strong abdominal breathing training as a novel intervention is based on previous work using head-down-only training and breathing-only training on motor and cognitive performance during DT. Head-down-only dynamic training and breathing-only training may improve motor and cognitive performance during DT to some extent. This is also the first attempt to utilise strong head-down abdominal breathing to treat a disease. Head-down strong abdominal breathing, a high-intensity exercise, improves cerebral blood flow and reduces psychological stress in older adults. High-intensity exercise (e.g. high-intensity breathing training) significantly improves physiological factors such as inspiratory muscle strength and endurance [80] in patients with COPD, which

helps individuals maintain normal tasks of daily living and contributes to the reduction of dyspnoea. Our goal was to explore the effects of strong head-down abdominal breathing on motor and cognitive performance during DT in patients with COPD. Based on our findings, we hypothesised that combining the two may have a positive effect on patients with COPD. Moreover, much of the current literature is based on differences in DT performance between patients with COPD and healthy individuals, such as balance and fall risk. Changes in brain regions during DT have also been explored using neuropsychological tools. Few studies have investigated the effects of exercise on DT performance in patients with COPD. One classic pulmonary rehabilitation (aerobic exercise) study discovered no improvement in gait speed or stride time variability during DT processing after pulmonary rehabilitation [45]. No rehabilitation measures have definitively improved DT performance in patients with COPD. Given the detrimental effect of DT performance on patients with COPD, this effect should be explored more deeply in the future to identify rehabilitation measures to improve DT performance in these patients.

Two overlapping theories have been established regarding the relative effects of fNIRS findings on cortical activity. The first theory suggests that decreased activity represents a decrease in the use of brain regions and, thus, an increase in efficiency [81]. The second suggests that increased cortical activity is a compensatory mechanism reflecting over-recruitment and reduced efficiency [81,82]. Over the past decades, studies have been published on brain activation during walking using fNIRS [83]. PFC activation is commonly described during walking tasks. The PFC plays an important role in planning complex cognitive behaviours, personality expression, and decision-making. As more brain resources are utilised during DT, the effects of DT interference are exacerbated when cognitive performance is impaired in diseases such as COPD, where oxy-Hb indices tend to be higher during DT than during ST. Previous research [19] discovered significantly higher oxy-Hb changes in the right dorsal PFC during preferred and fast-paced walking tasks in patients with COPD compared to healthy older adults. Reduced lung function is associated with greater increases in neural activity during the preferred walking DT in the right dorsal PFC. Cognitive decline in patients with COPD compared with older adults may contribute to the higher levels of neural activity required to perform individual tasks, resulting in higher oxy-Hb changes. Hyper-activation of the PFC may be exacerbated in patients with more severe cognitive impairment. Furthermore, patients with COPD have a fivefold higher fall rate than healthy adults [84]. These cognitive functions are needed more during simple walking, as well as during complex walking with higher balance requirements (e.g., when manoeuvring around obstacles). Patients with COPD have greater structural changes in the PFC than older adults. Performing challenging tasks requires more cognitive resources, resulting in increased blood flow to areas of high neural activity and a corresponding increase in oxygenated haemoglobin. Owing to limited cognitive resources, allocating them between tasks during DT may lead to errors in the execution of one or both tasks. Therefore, the present study is valuable for monitoring PFC activity during DT using fNIRS.

Motor performance requires the simultaneous use of cognitive and postural control. As attention is a finite resource, dividing attention between two simultaneous tasks can result in a decrease in performance on one or both tasks relative to when each task is performed separately (i.e., without competing attentional demands), especially when the attentional demands of one of the tasks are high. Individuals with neurological deficits are particularly vulnerable to DT interference [85]. This is especially true in patients with COPD, who have been documented to experience cognitive deficits that lead to changes in brain function, especially frontal lobe degeneration. The ability of patients with COPD to perform complex multitasking activities (e.g., driving or walking) while performing cognitive tasks is impaired [45,86]. The relative increase in the attentional demand to control motor performance indicates that fewer attentional resources are available to perform secondary tasks simultaneously. Furthermore, given the importance of community walking for participation and quality of life and the relevance of DT walking to daily community walking, DT walking performance is one of the rehabilitation outcomes for patients with neurological disorders. Therefore, our study discussing the effects of strong head-down abdominal breathing training on motor and cognitive performance during DT in patients with COPD is valuable. Simultaneously, our study is community-oriented, which can assist community activity centres and community hospitals in targeting this group and generalising it to the general public, reducing pressure on clinicians, especially for patients with mild COPD and cognitive impairment. With an aging population, community rehabilitation may gradually become a convenient and feasible pathway.

This study has some limitations. First, as our intervention, head-down strong abdominal breathing training, is a preliminary study, we did not consider the effect of changes in the intensity of the breathing intervention on patients with COPD. In previous studies, a lower intensity was initially set because of unadapted patients with COPD. As patients with COPD become more acclimatised, a lower intensity may not achieve the set goal. Additionally, the same intensity may not be appropriate for all patients owing to individual differences. This issue should be explored in more detail to increase the reliability of our results. Second, our study was conducted in one region and may not be representative of all patients with COPD. Future studies should expand the region and assess the effects of multicentre head-down strong abdominal breathing on motor and cognitive performance during DT in patients with COPD. Finally, our study only spanned 3 months, and the long-term effects on cognitive and motor performance during DT in patients with COPD are unknown. Future studies will explore the long-term compliance of patients and the long-term effects of head-down strong abdominal breathing on motor and cognitive performance during DT in patients with COPD by extending the duration of the intervention and follow-up assessments.

5. Conclusions

This study presents a novel intervention based on a simple and easy-to-administer approach to investigate the effects of head-down strong abdominal breathing intervention on motor and cognitive performance during DT in patients with COPD. As DT is more representative of daily life for patients with mild COPD, this intervention may improve their quality of life in the community and at home.

Ethics statement

The Ethics Committee of Anqing Normal University approved this project on 4 December 2023 (approval number: ANU2023002), and it was registered with the China Clinical Trial Registry (trial registration number: ChiCTR2400080452).

Data availability statement

No data was used for the research described in the article. Derived data supporting the findings of this study will be made available from the corresponding author on request because it includes residency and other privacy sensitive information.

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CRediT authorship contribution statement

Kexin Ding: Writing – original draft. **Feiyun Song:** Writing – review & editing. **Wei Qi:** Methodology. **Hongrui Liu:** Writing – review & editing. **Mingyun Sun:** Supervision, Methodology. **Rui Xia:** Funding acquisition.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Rui Xia reports financial support was provided by Department of Education Anhui Province. Mingyun Sun has patent #201821510570.5 licensed to Anqing Normal University. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e34255.

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